ERDC/CHL TR-08-16

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
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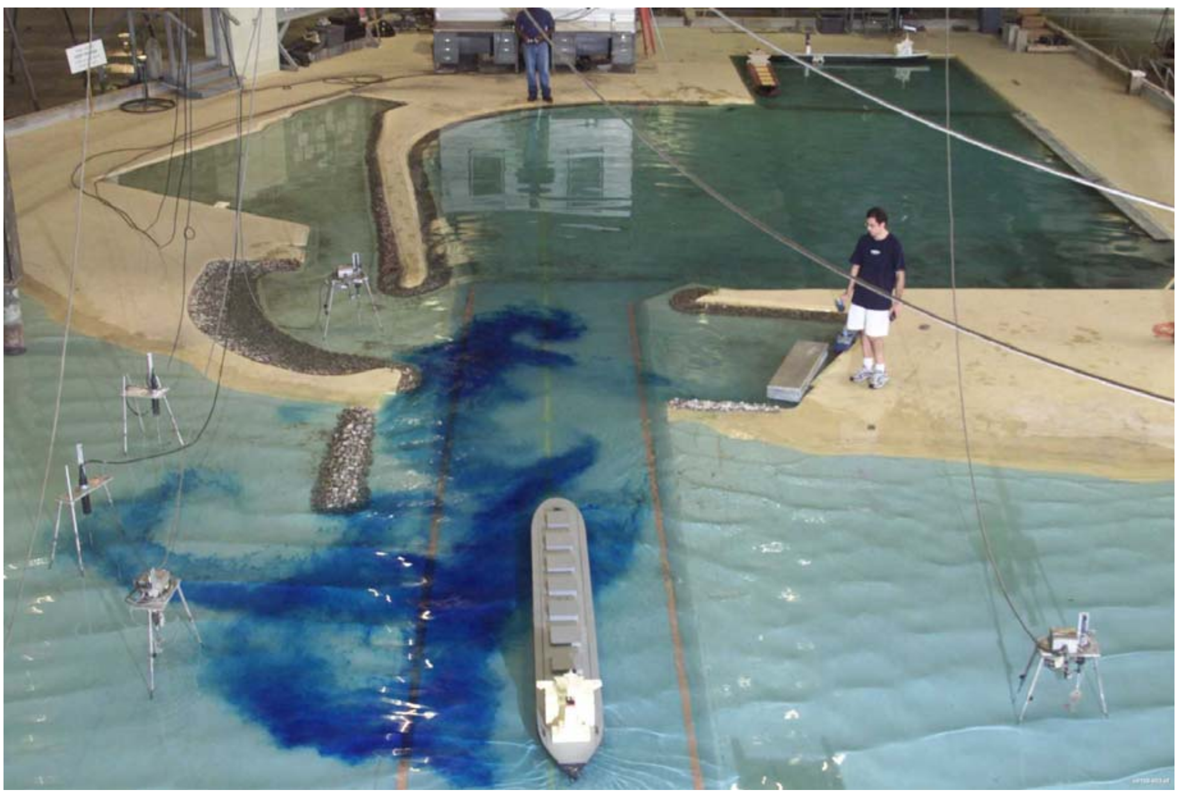
*Hydraulic Model Study*

# Barbers Point Harbor, Hawaii, Jetty Modification Study

Michael J. Briggs and Ivano Melito

November 2008



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Final report

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Prepared for U.S. Army Engineer District, Honolulu
Fort Shafter, HI 96858-5440

Under Hydraulic Model Study 007TFB

**Abstract:** A series of laboratory experiments were conducted for a range of model ships, irregular waves, wave-induced longshore currents, and jetty lengths to optimize the length of a proposed entrance channel jetty at Barbers Point Harbor, Hawaii. Eleven jetty configurations were studied on both sides of the entrance channel, with lengths varying from no-jetty to the proposed 450-ft length. Unidirectional spectral waves with wave periods of 6, 10, 14, and 18 sec, wave height of 7 ft, and incident wave directions of S25W (20 deg south of channel centerline) and S80W (35 deg west of channel centerline) were generated. Wave-induced ship motions were obtained for 392 inbound and outbound transits with 1:75 scale models of the APL *President Lincoln* C9-Class containership, a modified *Bunga Saga Empat* bulk-cargo carrier, and a *Kukahi* oceangoing barge. The 375-ft-long jetty on the north side of the channel and the 2-ft depth transition inside the harbor were recommended. This conclusion was based on (a) measured wave heights in the channel and barge basin, (b) ship and barge handling and maneuverability characteristics, (c) dye and current meter studies of the circulation patterns and flows in the channel, and (d) input from the sponsor, EPA, and harbor pilots.

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# Preface

In November 2000, the U.S. Army Engineer District, Honolulu (HED), requested assistance of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) in optimizing the required length of a proposed entrance-channel jetty at Barbers Point Harbor. Authorization for the CHL to perform the study was subsequently granted by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Physical model experiments were conducted at CHL during the period June to September 2001.

At the time this study was conducted, Acting Director of CHL was Thomas W. Richardson. Direct guidance was provided by Dennis Markle, Chief, Coastal Harbors and Structures Branch (HC-PH), CHL. Dr. Michael J. Briggs, HC-PH, was principal investigator for the study with responsibility for the overall study, model results, and report preparation. Ivano Melito, Contractor, assisted with model setup, data collection, and analysis. Robert Carver, HC-PH, was responsible for the model barge and jetty construction. Frank Sargent, HC-PH , assisted with the model ship calibration. Raymond Reed, HC-PH, was lead technician and piloted the model ships. Johnny Heggins, HC-PH, operated the wavemaker and collected wave data. Brandon Hansberry, Summer Intern, provided assistance with the model testing. David A. Daily, Tony Brogdon, and Tim Nisely, ERDC Information Technology Laboratory, provided instrumentation support.

A Progress Review Meeting was held at CHL during the study to witness model tests and review study results. Participating in this meeting were Stanley Boc, HED, Dr. Wendy I. Wiltse, U.S. Environmental Protection Agency (EPA), Capt. Dave Lyman, Hawaii Pilots Association (HPA), Capt. Thomas L. Heberle, HPA, and Capt. Warren B. Ditch, Jr., Hawaiian Tug and Barge.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4,046.873 | square meters |
| degrees (angle) | 0.01745329 | radians |
| feet | 0.3048 | meters |
| gallons | 3.785 | liters |
| Inches | 0.0254 | meters |
| knots | 0.5144444 | meters per second |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per foot | 14.59390 | newtons per meter |
| pounds (force) per inch | 175.1268 | newtons per meter |
| pounds (force) per square foot | 47.88026 | pascals |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (mass) | 0.45359237 | kilograms |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic meter |
| pounds (mass) per cubic inch | 2.757990 E+04 | kilograms per cubic meter |
| pounds (mass) per square foot | 4.882428 | kilograms per square meter |
| pounds (mass) per square yard | 0.542492 | kilograms per square meter |
| square feet | 0.09290304 | square meters |
| tons (force) | 8,896.443 | newtons |
| tons (force) per square foot | 95.76052 | kilopascals |
| tons (long) per cubic yard | 1,328.939 | kilograms per cubic meter |
| tons (nuclear equivalent of TNT) | 4.184 E+09 | joules |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |
| tons (2,000 pounds, mass) per square foot | 9,764.856 | kilograms per square meter |

# Executive Summary


## Background

In November 2000, the U.S. Army Engineer District, Honolulu (HED), requested assistance of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) in optimizing the required length of a proposed entrance-channel jetty at Barbers Point Harbor. Proposed project modifications included (a) reducing the depth transition between the entrance channel and the harbor from 4 ft to 2 ft and moving it from the shoreline to back inside the harbor and (b) constructing a 450-ft-long jetty from shore on the north side of the entrance channel.

Briggs et al. (1994) recommended a 450-ft-long jetty on the north side of the entrance channel to provide shelter from waves from the west and longshore crosscurrents near the shore. They also demonstrated that a 450-ft-long jetty would provide minimum risk of groundings for the design ship. Harkins and Dorrell (2000) conducted additional laboratory experiments and recommended reducing and moving the depth transition between the channel and the harbor from the shoreline farther into the harbor to improve inbound ship transits. The purpose of this study was to determine if the jetty is still required if the depth transition modifications are implemented, and if so, what is the minimum length required.

## Physical model

In summer 2001, a series of laboratory experiments were conducted for a range of model ships, wave conditions, and jetty lengths. The existing physical model of Barbers Point Harbor (1:75 scale) was used with models of the APL *President Lincoln* C9-Class containership, a modified *Bunga Saga Empat* bulk-cargo carrier, and a *Kukahi* oceangoing barge. The *President Lincoln* is more responsive to waves than the *Bunga Saga Empat*. The 2-ft depth transition between the harbor and the channel was located back in the harbor entrance, and the water depth was set at 44 ft in the entrance channel. Ship drafts were 39 ft, for a maximum channel underkeel clearance of 5 ft. Unidirectional spectral waves with wave periods of 6, 10, 14, and 18 sec, wave height of 7 ft, and incident wave directions of S25W (20 deg south of channel centerline) and S80W (35 deg

west of channel centerline) were generated. Jetty configurations varied between no-jetty and the proposed 450-ft length.

## Test plan

The model study consisted of four phases: (a) calibration, (b) production, (c) pilot, and (d) optimization. In the Calibration Phase, seven capacitance wave gages were used to iteratively match target wave parameters. Four gages were located outside the channel and three gages were positioned along the length of the channel. Target wave parameters were calibrated at the wave gage outside the channel in the 32-ft water depth (similar to earlier laboratory studies). For the S80W wave direction, the four waves were calibrated with the no-jetty configuration. For the S25W wave direction, no attempt was made to recalibrate the control signals, although the waves were measured with the no-jetty, 225-ft, and 450-ft jetty lengths as baseline conditions. Several additional runs were conducted with two current meters for the no-jetty configuration. These current meters were positioned on the channel centerline at the projection of the no-jetty and the 450-ft-long jetty, with current measurements at mid-depth in the channel. Ship speed trials were conducted to calibrate ship speeds to the remote control settings. Target ship speeds were 5 kts and ranged between 4.3 to 6.7 kts. The *Kukahi* barge speeds ranged between 3.1 to 3.9 kts.

In the Production Phase, the model *President Lincoln*, *Bunga Saga Empat*, and *Kukahi* made a total of 392 inbound and outbound transits. First, the S80W wave direction cases were studied for jetty lengths of 0, 225, and 450 ft. In general, each ship experienced four round trips for each wave condition and jetty length combination. The three channel wave gages were removed for this phase and data were collected with only the four remaining outside wave gages. Dye, overhead camera, and visual observations were used to monitor wave-induced current flows during these ship transits. Next, the wavemaker was repositioned to reproduce the S25W waves. A total of 123 transits were made with the *Bunga Saga Empat* and the *Kukahi* for the no-jetty and 450-ft jetty configurations. Data were collected with the four wave gages. Qualitative measurements were made with the dye, overhead camera, and visual observations.

In the Pilot Phase (Progress Review Meeting), the harbor pilots conducted a series of experiments with all three vessels for S25W waves. In addition to jetty lengths of 0, 225, 300, 375, and 450 ft on the north side of the channel, several jetty lengths (225 and 450 ft) on the south side were also investigated. Dye was used to visualize the current patterns. Participating in and witnessing these tests were Stan Boc, HED, Dr. Wendy I. Wiltse, U.S. Environmental Protection Agency (EPA), Capt. Dave Lyman, Hawaii Pilots Association, Capt. Thomas L. Heberle, Hawaii Pilots Association, and Capt. Warren B. Ditch, Jr., Hawaiian Tug and Barge.

Based on the results from the pilot phase, a minimum length of at least 375 ft was believed to provide needed navigation safety. This conclusion was a compromise between safe navigation considerations, pilot observations of ship handling, and environmental concerns. The purpose of the Optimization Phase was to further optimize the jetty length by studying the current magnitudes in the entrance channel for four jetty lengths: 375, 400, 425, and 450 ft. Four current meters were placed, one every 50 ft along the channel centerline, at locations corresponding to jetty lengths of 300 to 450 ft. Wave data were recorded at seven locations: (a) three outside the channel to measure incident wave conditions, (b) three along the channel centerline at locations of 0, 225, and 525 ft relative to the jetty origin, and (c) one in the north corner of the barge basin (similar to the 1992 study). The same four wave cases from the S25W wave direction were used. Two repeat runs were made with each wave. No additional navigation tests were conducted in this phase of the study.

## Results

This section contains a summary of the results from the different study phases relative to wave heights, ship response, circulation patterns, sponsor and pilot input, and jetty length optimization.

### Wave heights

Although the three channel gages are in a constant water depth, they do experience some wave transformation due to the changing water depths outside the channel and the channel sides. As expected, there were some variations in the measured wave heights $H_{mo}$ in the channel as a function of peak wave period $T_p$ and wave direction $\theta_m$ (from S25W to S80W waves). As $T_p$ increases, $H_{mo}$ tends to decrease for locations closer to shore. Also, the reduction in $H_{mo}$ is slightly greater for the waves from S25W.

In general, there were only small differences in the measured wave heights in the channel due to changes in the jetty lengths for waves from S25W. Thus, a change in the jetty length will not significantly modify the wave height in the channel.

For waves from S25W, there were no significant differences in the measured $H_{mo}$ in the barge basin due to jetty lengths from 375 to 450 ft. For incident $H_{mo}$ of 6.1 to 7.6 ft, the average $H_{mo}$ in the barge basin was near 1 ft for all jetty lengths and wave periods.

### Ship response

Since the *President Lincoln* is a more streamlined ship than the *Bunga Saga Empat*, it responded more to the waves. As a result it experienced more rolling and yawing near the shoreline, where a jetty would afford additional protection. Neither ship experienced any dangerous conditions that would have led to a grounding incident due to insufficient underkeel clearance or channel width. The *Bunga Saga Empat*, especially, seemed to be unaffected by the wave conditions studied. The *Kukahi* barge, however, did experience many problems with sway and yaw that caused it to meander all over the width of the channel. The jetty did provide needed shelter for the *Kukahi* barge near the shoreline.

### Circulation patterns

Flow patterns due to wave-induced longshore currents in the vicinity of the proposed jetty are very complex due to the bathymetry and the channel proximity. The pilots have long observed crosscurrents in the channel near the shoreline that tend to yaw the vessels as they approach the harbor entrance.

In general, the longshore current flows across the channel toward the proposed jetty site on the north side of the entrance channel due to refraction and diffraction. This flow is interrupted with a jetty in place, with flow being diverted around the jetty and continuing along the coastline. Some crosscurrents or shears will continue to exist in the entrance channel even with the jetty, but they are moved farther offshore and reduced in magnitude relative to the no-jetty configuration.

### Sponsor and pilot input

Based on study results and the progress review meeting, the consensus was that at least a 375-ft-long jetty was required. This jetty length was based on (a) the handling of the model ships for the different wave and jetty lengths tested, (b) the experience of the Hawaiian pilots, (c) circulation patterns in the channel and relative magnitudes of crosscurrents, and (d) minimized jetty construction costs.

### Jetty length optimization

The Optimization Phase was conducted to determine if this 375-ft jetty length could be optimized further. Previously, only jetty lengths of 225, 300, 375, and 450 ft had been studied. Thus, jetty lengths of 375, 400, 425, and 450 ft were investigated to fill in the gaps between jetty lengths of 375 and 450 ft. Current magnitudes, cross-channel velocity components, and magnitude differences relative to the no-jetty configuration were calculated for the four current meter locations in the entrance channel. Current magnitudes were between 1 to 2 kts. The direction was more “to and fro” aligned with the wave direction for the smaller wave period of $T_p$=6 sec and turned more westerly and normal to the channel centerline as the wave period increased.

In general, there was very little variation in wave height or current magnitude and direction as a function of wave period, jetty length, and location. There was no clear cut “winner” based on the jetty configurations tested in this study. Some jetty lengths were slightly better than others for different wave periods and locations in the channel. The even-odd analysis indicated that the 375-ft jetty was the better choice.

## Conclusion

Based on results for the wave conditions and jetty lengths studied, the 375-ft-long jetty and the 2-ft depth transition inside the harbor are recommended. The distance from the old transition at the shoreline to the new transition in the harbor is approximately equal to a ship length. Thus, the effect of the shear on the ship as it moves over the abrupt vertical change in bottom elevation is minimized by moving this transition back into the harbor. The combination of the 375-ft jetty and modified location and height of the channel transition will provide sufficient sheltering from the waves and currents near the shoreline. The input from the harbor pilots was instrumental in selecting a minimum jetty length of 375 ft, based on the ship and barge responses. This conclusion is based on (a) measured wave heights in the channel and barge basin, (b) ship and barge handling and maneuverability characteristics, (c) dye and current meter studies of the circulation patterns and flows in the channel, and (d) input from the sponsor, EPA, and (e) expert opinion from the harbor pilots. In combination with the modified depth transition, the shorter 375-ft-long jetty will provide the needed navigation sheltering from waves and currents.

# 1 Introduction

## The prototype

Barbers Point Harbor, Hawaii, is located on the southwest coastline of Oahu and consists of a deep-draft harbor, barge basin, resort marina, and entrance channel. Aerial and overhead views are shown in Figure 1. The deep-draft harbor has an area over 90 acres and is 38 ft deep. Rubble mound wave absorbers line approximately 3,700 ft of the harbor basin. A new harbor expansion (550 ft wide by 1,100 ft deep) in the northeast corner of the harbor basin was built in 2000. The barge basin is 220 ft by 1,300 ft and 23 ft deep MLLW[1]. The West Beach Marina (WBM) was opened in July 1989. It has a depth of 15 ft and was designed to accommodate 350 to 500 small boats. The entrance channel is 450 ft wide, 3,100 ft long, and 42 ft deep. The harbor regularly services barges, tankers, and bulk carriers.

## Background

Briggs et al. (1994) recommended a 450-ft-long jetty on the north side of the entrance channel (as part of plan 4c recommendations) to provide shelter from waves from the west and longshore crosscurrents near the shore. Briggs et al. (1994) noted that the 450-ft jetty along the north side of the channel improved wind-wave conditions within the harbor, especially at the barge basin, and eliminated an existing crosscurrent at the shoreline. Furthermore, the jetty was shown to have minimal effect on harbor surge response.

Harkins and Dorrell (2000) conducted additional laboratory experiments and recommended reducing and moving the depth transition between the channel and the harbor from the shoreline farther into the harbor to improve inbound ship transits.

In November 2000, the U.S. Army Engineer District, Honolulu (HED), requested assistance of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) in optimizing the required length of the proposed entrance-channel jetty at Barbers Point Harbor. Proposed project modifications included the following:

[1] All elevations are referenced to mean lower low water.


(a) Aerial view.

(b) Overhead view.

Figure 1. Barbers Point Harbor, HI, aerial photographs.

- Constructing a 450-ft-long jetty from shore on the north side of the entrance channel.
- Reducing the depth transition between the entrance channel and the harbor from 4 ft to 2 ft and moving it from the shoreline to back inside the harbor.

The proposed 450-ft-long jetty will cost approximately $3M to construct. It was felt that these transition modifications and a shorter jetty may provide adequate protection. Thus, the physical model was reactivated and a study was conducted in summer 2001 to optimize the jetty length.

## Purpose

The purpose of this study was to determine the need for a proposed jetty in Barbers Point Harbor entrance channel. If a jetty is needed, the studies will provide data to assist in optimizing the jetty length.

## Test plan

The model study consisted of four phases: (a) calibration, (b) production, (c) pilot, and (d) optimization. The Calibration Phase consisted of iterative corrections to the wavemaker control signals to match target wave conditions, and speed trials were conducted to calibrate the remote control speed settings for the three vessels selected for study. In the Production Phase, the model *President Lincoln*, *Bunga Saga Empat*, and *Kukahi* made a total of 392 inbound and outbound transits. Dye, overhead camera, and visual observations were used to monitor wave-induced current flows and ship response during these ship transits. In the Pilot Phase, the harbor pilots conducted a series of experiments with all three vessels for S25W waves. In addition to jetty lengths of 0, 225, 300, 375, and 450 ft on the north side of the channel, two jetty lengths (225 and 450 ft) on the south side were also investigated. The purpose of the optimization phase was to further optimize the jetty length by studying the current magnitudes in the entrance channel for four jetty lengths of 375, 400, 425, and 450 ft, located on the north side of the channel.

## Report organization

This report describes a physical model investigation of the Barbers Point Harbor to optimize the length of a proposed jetty. Chapter 2 describes the physical model including design, instrumentation, and vessels. A description of the study procedures is given in Chapter 3. The model calibration, including wave environment and speed trials, is described in Chapter 4. In Chapter 5, results are presented and discussed. Finally, Chapter 6 presents conclusions and recommendations.

# 2 Physical Model

## Model design

### Model layout

The existing physical model of Barbers Point Harbor (Briggs et al. 1994; Harkins and Dorrell 2000) was reactivated and used in this study (Figure 2). It is an undistorted, three-dimensional model of the harbor complex, at a model to prototype scale $L_r$ = 1:75. The model was operated in accordance with Froude's model laws. The nearshore area extends to the 100-ft contour and includes approximately 3,500 ft of shoreline on either side of the entrance channel. Total area of the model is over 11,000 ft². The basin was lined with wave absorber material to minimize reflections from the basin boundaries.

Figure 2. Physical model of Barbers Point Harbor.

A schematic of the model layout is shown in Figure 3. The channel centerline is aligned in a northeast-southwest direction of approximately S45W, or 45 deg from true north. Channel stations are located every 100 ft in the entrance channel for both the model and the prototype. The offshore station 0 is the origin. Station 33 (i.e., 3,300 ft toward the harbor from station 0) corresponds to the original depth transition location near the shoreline. The local, right-handed coordinate system for this study has its origin at station 0. The positive x-axis points into the harbor (i.e., increasing station numbers, or to the northeast) and the positive y-axis points to the northwest. The positive z-axis is upward from the water surface.

The existing prototype harbor and channel have water depths of 38 and 42 ft, respectively. The existing model, however, had a 45-ft harbor (the recommended depth in plan 4c, Briggs et al. 1994) and 42-ft channel depths. The entrance channel had been restored to existing conditions for use in validation studies, but the harbor had been left in its deepened condition. Harkins and Dorrell (2000) had recommended a minimum 5 ft underkeel clearance in the entrance channel for a ship draft of 39 ft. This would necessitate a 2-ft increase in the channel depth to 44 ft. Rather than make modifications to the physical model, it was decided that raising the water level by 2 ft was a more expeditious solution to meet time and funding constraints. Thus, water depths in the model were set at 44 ft in the channel and 47 ft in the harbor. The effect of the deeper harbor was felt to have a minor effect on the ship response and jetty optimization because of its location away from the jetty.

The existing prototype has a depth transition marking the end of the harbor and the beginning of the channel located near the shoreline. It has a vertical change of 4 ft (i.e., 38-ft harbor to 42-ft channel). Harkins and Dorrell (2000) had also recommended moving the depth transition farther inside the channel from the shoreline to the harbor edge of the barge basin. This new placement of the depth transition allows at least one ship length between the harbor and the shoreline. All experiments in this study were conducted with this new depth transition location. In other words, the channel depth was uniform throughout from offshore to the entrance to the harbor at the northern end of the barge basin.

In 2000, an abbreviated harbor expansion (i.e., 550 ft wide by 1,100 ft deep) was constructed in the prototype that is only half as wide as originally proposed (i.e., 1,100 ft by 1,100 ft). However, the model includes the full harbor expansion. This was not felt to have a significant effect on these tests since the expansion is located in the back part of the harbor away from the channel and jetty.

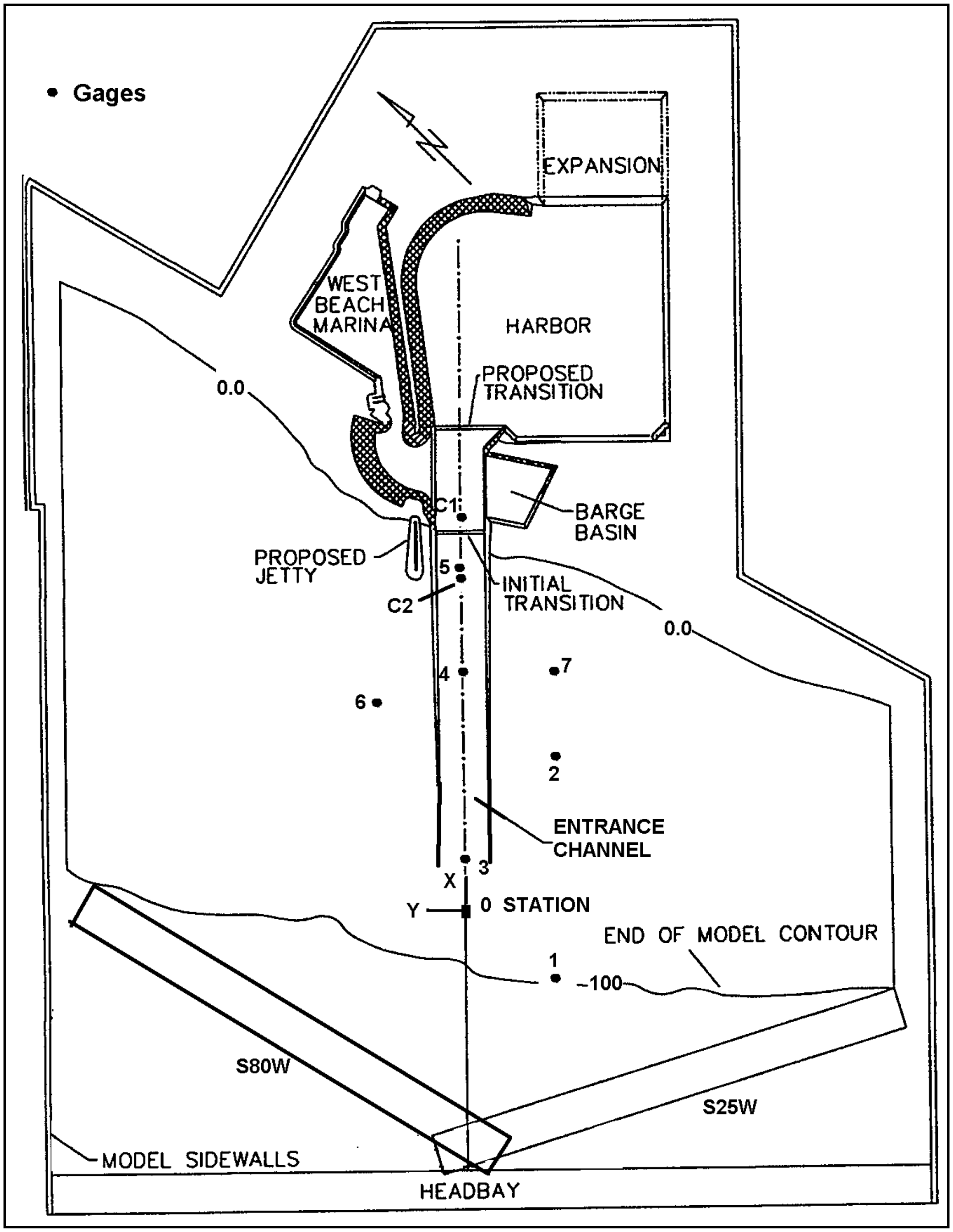



Figure 3. Schematic of physical model.

### Jetty design

A typical jetty cross section was used. The proposed jetty (Figure 4) was constructed with 10- to 12-ton fitted armor stone. This armor layer had a thickness of 10 ft, a crest height of 10 ft, a crest width of 15 ft (i.e., three armor stones), and side slopes of 2 horizontal to 1 vertical. The interior core material consisted of 5- to 2,000-lb stone. The jetty was offset from the edge of the channel approximately 50 ft from the north side of the channel. This distance provided a standoff distance between the toe of the jetty and the edge of the channel. It was not within the scope of this study to optimize the jetty cross section or offset distance. Additional stability tests would be required to optimize jetty characteristics and offset distances from the channel sides.

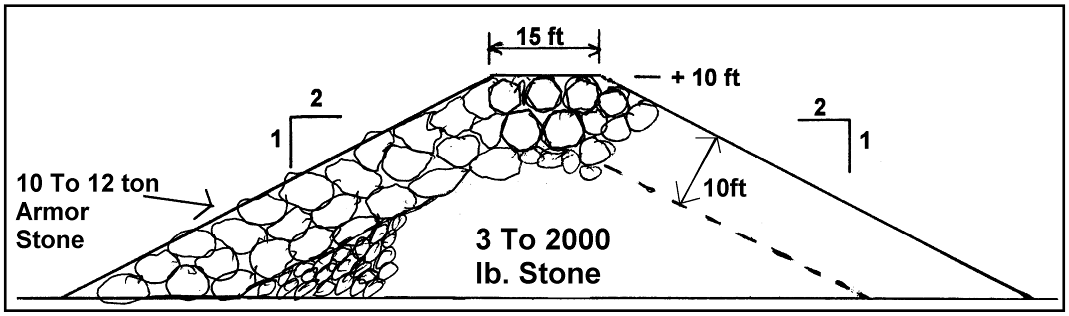



Figure 4. Typical jetty cross section.

## Model appurtenances

### Wavemaker

Model waves were generated with a unidirectional, plunger wavemaker. This electro-hydraulic wavemaker is 60 ft long, with a trapezoidal-shaped plunger. The plunger is 1.16 ft high and 1.14 ft wide at the top, tapering to zero at the bottom. The maximum stroke is 0.83 ft. The still-water level (SWL) was set at 0.41 ft from the base of the plunger to allow use of the entire stroke.

### Instrumentation

Both ERDC-designed capacitance wave gages and SonTek current meters were used in this study.

*Capacitance wave gages*

Seven capacitance wave gages were placed in the model to measure water surface elevations. Two gage setups were used. The first gage setup was used during both the Calibration Phase and the Production Phase. The second gage setup was used during the Optimization Phase. Table 1 lists the gages and locations for each gage setup.

Table 1. Wave gage model and prototype coordinates.

| Gage | Name | Model, ft | | | Prototype, ft | | |
|---|---|---|---|---|---|---|---|
| | | X | Y | Depth | X | Y | Depth |
| Calibration Phase and Production Phase | | | | | | | |
| 1 | Incident-Deep | -15.70 | -11.50 | 1.36 | -1178 | -863 | 102 |
| 2 | Incident-East | 17.66 | -11.50 | 0.43 | 1325 | -863 | 32 |
| 3 | Channel Offshore | 4.23 | 0.00 | 0.59 | 317 | 0 | 44 |
| 4 | Channel Middle | 29.16 | 0.00 | 0.59 | 2187 | 0 | 44 |
| 5 | Channel Jetty Head | 39.64 | 0.00 | 0.59 | 2973 | 0 | 44 |
| 6 | Incident-West | 20.92 | 11.80 | 0.39 | 1569 | 885 | 27 |
| 7 | Shallow-East | 29.16 | -11.50 | 0.29 | 2187 | -863 | 22 |
| Optimization Phase | | | | | | | |
| 1 | Incident-Deep | -15.70 | -11.50 | 1.36 | -1178 | -863 | 102 |
| 2 | Incident-East | 17.66 | -11.50 | 0.43 | 1325 | -863 | 32 |
| 3 | Channel Jetty Head | 38.12 | 0.00 | 0.59 | 2859 | 0 | 44 |
| 4 | Channel Jetty Middle | 42.12 | 0.00 | 0.59 | 3159 | 0 | 44 |
| 5 | Channel Jetty Shore | 45.12 | 0.00 | 0.59 | 3384 | 0 | 44 |
| 6 | Incident-West | 20.92 | 11.80 | 0.39 | 1569 | 885 | 30 |
| 7 | Barge-North | -0.45 | -4.95 | 0.33 | -34 | -371 | 25 |

Notes:
1. Right-handed coordinate origin at station 0 and channel centerline.
2. Positive x-axis points to harbor, positive y-axis to west.
3. Depth includes +2 ft additional water level.

In the first setup (Figure 3), three wave gages (1, 2, and 7) were located parallel and east of the entrance channel, three (3, 4, and 5) on the channel centerline, and one (6) on the west side. Gage 1 was positioned at the 100-ft contour to measure deep water wave conditions. Gage 2 was used to measure incident wave conditions and was located at the 30-ft contour at the same location as the middle gage in Harkins and Dorrell (2000). Gage 3 was positioned at the channel “daylight” near the offshore entrance. Gage 4 was located near station 20 and gage 5 was on the projection of the 450-ft jetty with the channel centerline. Gage 6 was a backup gage for incident wave conditions on the 27-ft contour in the same position as the $S_{xy}$ gage from the Briggs et al. (1994) study. Finally, gage 7 was in line with gage 4, but on the east side of the channel.

In the second setup (Figure 5), gages 1, 2, and 6 remained unchanged. Gages 3, 4, and 5 were repositioned inside the channel for better definition of wave conditions in the vicinity of the proposed jetty. Gage 7 was moved to the northeast corner of the barge basin to measure its response to the different jetty lengths.

The measurement rods on these gages had a variable length depending on water depth. They were calibrated every day prior to conducting tests. The gages were raised and lowered through a series of 21 steps using Jordan controller stepper motors. A linear, least squares averaging technique was used to obtain the calibration coefficients. Data were sampled at a rate of 10 Hz.

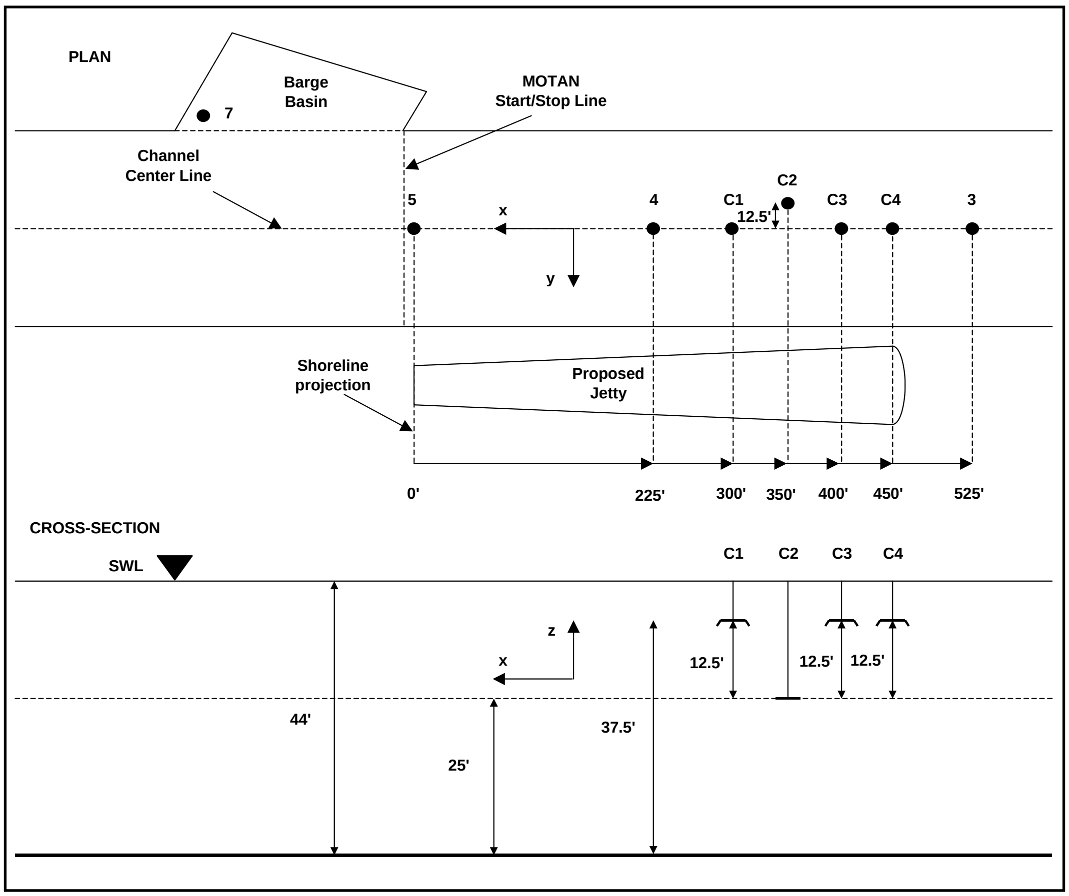



Figure 5. Second gage setup, Optimization Phase, numbers for wave gages and C for current meters.

### *ADV current meters*

Four Acoustic Doppler Velocimeter (ADV) current meters were used to measure longshore current velocities. The ADVs operate on the Doppler principle. An acoustic pulse is transmitted by the transducer, reflected from particles in the water, and sensed by the receivers. The speed of the water is calculated by calculating the shift in the signal frequency. Seeding material was added to the water prior and during data collection to insure a strong signal-to-noise ratio (SNR). The SNR needs to be above 5 dB for mean data (i.e., 10-sec averages) and 15 dB for raw data. This seeding material consists of neutrally buoyant, hollow spheres with a 10-μm diameter.

These meters (Figure 6) consist of an ADV sensor, probe, signal-conditioning module (SCM), high frequency cable (HFC), and PC-card processor (SonTek 1997). Three different probes were used in this study: a 2D side-looking probe, a 3D up-looking probe, and a 3D down-looking probe. The ADV sensor consists of one acoustic transmitter and two or three receivers, depending on whether a 2D or 3D probe is used. The probe includes the sensor, a 1.31-ft-long by 0.31-in. diameter stem, and an endbell. The middle of the sampling volume of each probe is positioned approximately 2 in. to the side of the 2D probe, or 2 in. above the (up-looking) or below (down-looking) 3D probes. The probe is attached to the 0.94-ft-long by 0.17-ft diameter SCM that contains a receiver in the waterproof housing. Finally, the HFC transmits the data to the processor in the SonTek analysis PC for processing by the ADVLab analysis software.

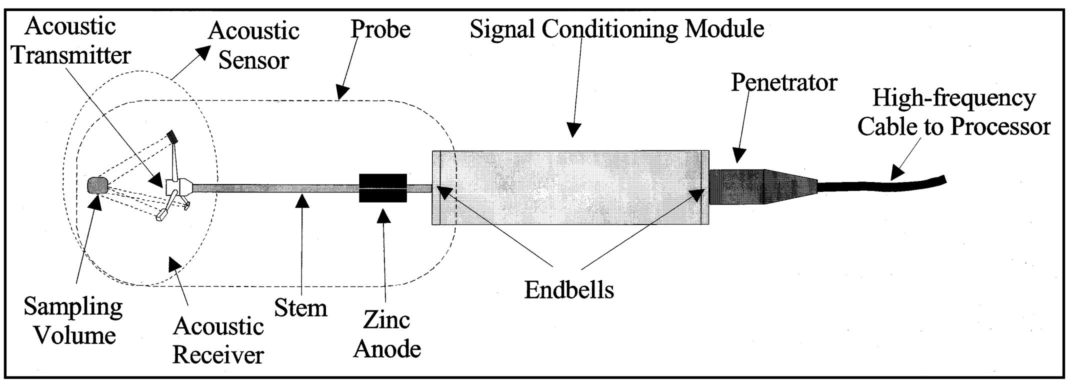



Figure 6. ADV current meters (courtesy of SonTek 1997).

The ADVs are calibrated at the factory and do not require additional calibration unless damaged. Since temperature affects the speed of sound, the only required input is the water temperature on a daily basis. The velocity resolution of the ADVs is 0.004 in./sec and the accuracy is 1 percent of measured velocity. Although a data sampling rate of 25 Hz is recommended when collecting data for turbulence structure analysis, it was felt that a sampling rate of 10 Hz (same as wave gages) for 1,200 sec was sufficient for this study. The first Calibration Phase Run 05 was collected at 25 Hz in units of feet per second. Subsequent runs were collected for 10 Hz in units of centimeters per second.

Figure 7 shows the right-handed coordinate systems used for the 2D and 3D probes. Positive x-velocity is in the direction of the positive x-axis, denoted by the red-painted arm on each meter. Positive y-velocity is in the direction of the positive y-axis, 90 deg to the left of the x-axis (i.e., splitting the transducer beams). Thus, the right-hand coordinate system for the current meters was located on the channel centerline with the positive x-axis pointing toward the harbor and the positive y-axis toward the jetty (i.e., west). For the 3D probes, positive z-velocity is up.

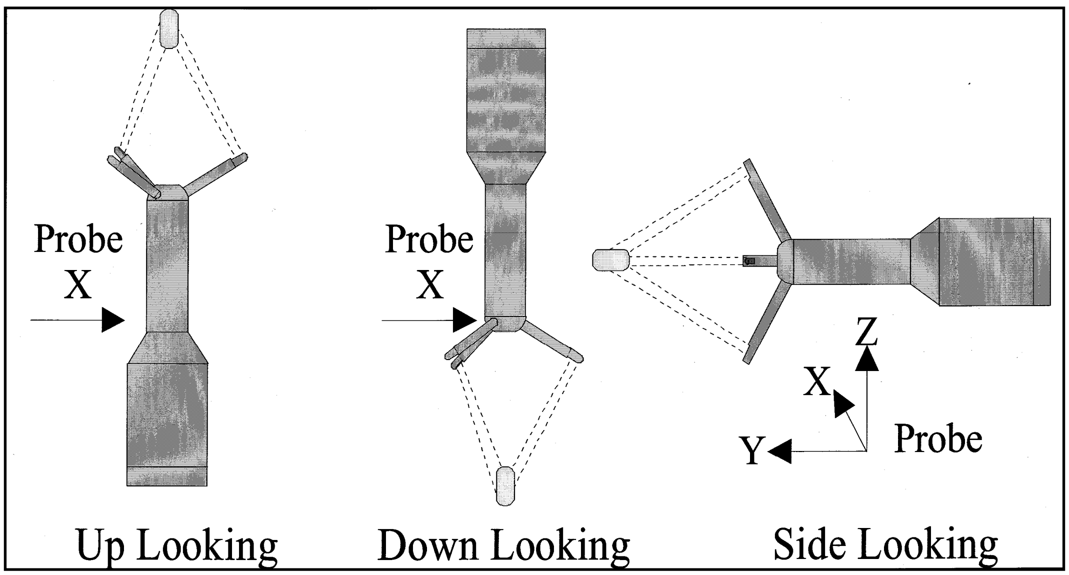



Figure 7. Current meter coordinate system (courtesy of SonTek 1997).

The ADVs were located on tripod stands along the channel centerline with the tripod legs aligned so that they were not in line with the principal direction of flow (i.e., parallel to the channel). The measuring volume of the probes was positioned slightly above mid-depth, at 25 ft from the bottom (denoted by C1 to C4 in Figure 5). This corresponds to a depth of 19 ft below the water surface. Since the water particle velocity decreases with depth, this location was selected to measure the largest current magnitude while still insuring that the probe remained submerged during passage of the troughs for the largest waves. The measurements represent "point" measurements and not averages over depth. The water around each meter was extensively and continuously seeded during the tests to insure good SNRs.

Two current meter setups were used during the study. The first setup was used in the Calibration Phase and the second setup during the Optimization Phase. Only two ADVs were used in the first setup. Table 2 lists the ADV types, orientations, and locations for each setup. The number in parenthesis in the "Probe" column is the distance measured offshore along the channel centerline from the base of the jetty at the shoreline.

Table 2. Current meter model and prototype coordinates.

| Gage | Probe | Type | Gage +X | Model, ft | | | Prototype, ft | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | X | Y | Depth | X | Y | Depth |
| Calibration Phase | | | | | | | | | |
| C1 | 0 (0 ft) | 3U | Offshore | 45.12 | 0.00 | 0.33 | 3384 | 0 | 25 |
| C2 | 1 (450 ft) | 2S | Offshore | 39.12 | 0.00 | 0.33 | 2934 | 0 | 25 |
| Optimization Phase | | | | | | | | | |
| C1 | 0 (300 ft) | 3U, 3D | Harbor | 41.12 | 0.00 | 0.33 | 3084 | 0 | 25 |
| C2 | 1 (350 ft) | 2S | Harbor | 40.45 | 0.00 | 0.33 | 3034 | 0 | 25 |
| C3 | 2 (400 ft) | 3D | Harbor | 39.79 | 0.00 | 0.33 | 2984 | 0 | 25 |
| C4 | 3 (450 ft) | 3D | Harbor | 39.12 | 0.00 | 0.33 | 2934 | 0 | 25 |

Notes:
1. Right-handed coordinate origin at station 0 and channel centerline.
2. Positive x-axis points to harbor, positive y-axis to west, positive z-axis up.
3. Type = Type of current meter, 2S = 2D side, 3D = 3D down, 3U = 3D up.
4. Gage +X = Orientation of positive x-axis, offshore = points offshore, harbor = points to harbor.
5. Depth = Depth above bottom.
6. Changed C1 to from 3U to 3D on 27 Aug 01, for Runs 33 and 34. 3U was positioned 25 ft below the 3D level (12.5 ft from the bottom) so that the measurement volume was centered at 25 ft from the bottom (same as other current meters).

### Computer support

The computer system in the control room provided computer support for the experiments. It consists of three personal computers (PCs). One of the PCs provided (a) calibration, command, and feedback of the wavemaker, and (b) calibration and data collection of the wave gages. The second PC provided control signal generation and data analysis using the GEDAP software system (Miles 1997). A third PC was installed on-site at the model to record the current meter data from the SonTek current meters using their ADV software. All three computers were able to communicate with one another through a fiber-optic network and were time-synchronized.

### Water level controller

Water level was maintained to within ±0.002 ft using a point gage and an automatic water level float with solenoid valve. This controller was located on the basin perimeter wall near the intersection of the 100-ft bathymetric contour with the southeast corner of the basin. Water lines and drains were located nearby to facilitate adjustments if necessary. Water levels were checked several times a day during testing to insure precise control.

## Model vessels

Two model ships and an oceangoing barge were selected for study, based on discussions with HED and the available CHL inventory of model vessels. The two ships were the *President Lincoln*, an American President Lines (APL) C9-class container ship, and a modified *Bunga Saga Empat*, a bulk-cargo carrier. The two ships have different hull shapes and wave and current responses. The *President Lincoln* is more streamlined than the *Bunga Saga Empat*. The *Bunga Saga Empat*, however, was tested more extensively than the *President Lincoln* because it is more representative of actual shipping at Barbers Point Harbor. The barge was modeled after the barge *Kukahi*. All model vessels (i.e., two ships and barge) were constructed at the same 1:75 scale as the physical model.

### Vessel descriptions

*President Lincoln container ship*

The *President Lincoln* was built in the early 1980s and is currently one of the larger containerships on the Pacific Rim trade routes. This was the “design” ship used in the previous study by Briggs et al. (1994). The ship has a length of 860 ft, a beam of 106 ft, a draft of 39 ft, and a displacement of 55,000 long tons. The ship draft was set at 39 ft, for a maximum channel underkeel clearance of 5 ft.

The model ship (Figure 8) had remote-controlled forward and reverse speeds, rudder angle, and bow thruster direction and speed. It was powered by a 12-volt battery.

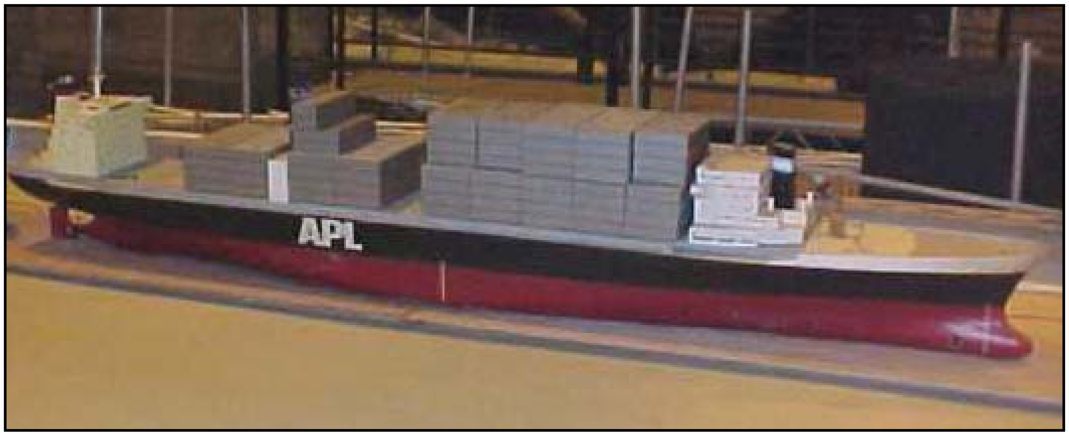



Figure 8. Model APL *President Lincoln* container ship.

*Bunga Saga Empat bulk carrier*

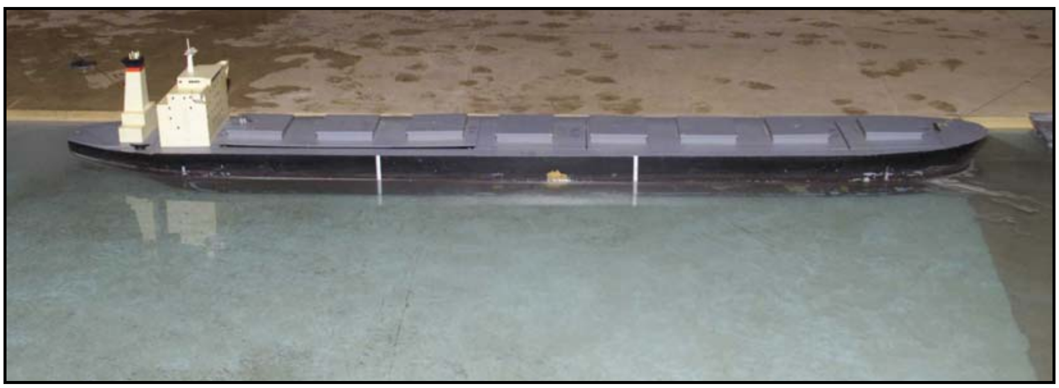
The modified *Bunga Saga Empat* has a length of 850 ft (modified length is 100 ft longer than actual vessel), a beam of 106 ft, and a draft of 39 ft. Prototype and model *Bunga Saga Empat* vessels are shown in Figure 9. A 12-volt battery powered the remote-controlled forward and reverse speeds and rudder angle. This was the “design” ship used in the previous study by Harkins and Dorrell (2000).

*Kukahi barge*

The *Kukahi* is representative of the small oceangoing barges that use Barbers Point Harbor (Figure 10). It has a length of 310 ft, beam of 76 ft, and height of 21 ft. Empty draft is 4.25 ft with a tare weight of 3,000 tons and maximum draft is 16.9 ft with a full load of 9,000 tons. Based on discussions with the harbor pilots, a draft of 13.5 ft was selected for the barge. This was felt to be the worst-case configuration relative to its handling characteristics in waves. The *Kukahi* barge has two skegs on the stern for control and stabilization. Port Captain, Warren Ditch, provided input on the barge design.

The *Kukahi* model was fabricated at ERDC using lightweight aluminum. A removable cover was made to keep water from splashing inside the open hull. The *World Utility* ship was used as a towboat since CHL does not have any oceangoing towboats in its inventory. A Y-shaped towing bridle was simulated using a retractable holder and nylon fishing line. The 200-ft-long towline consisted of a fixed 100-ft-long segment and a 100-ft-long retractable segment. This arrangement approximated the natural spring and damping of a real towline.

(a) Prototype.



(b) Model.

Figure 9. *Bunga Saga Empat* bulk-cargo carrier.

### Vessel calibration

The model vessels were statically and dynamically calibrated to insure proper Froude scaling. Both model ships had been used in previous studies (Briggs et al. 1994; Harkins and Dorrell 2000), so information on weight distribution and dynamic response characteristics was available.

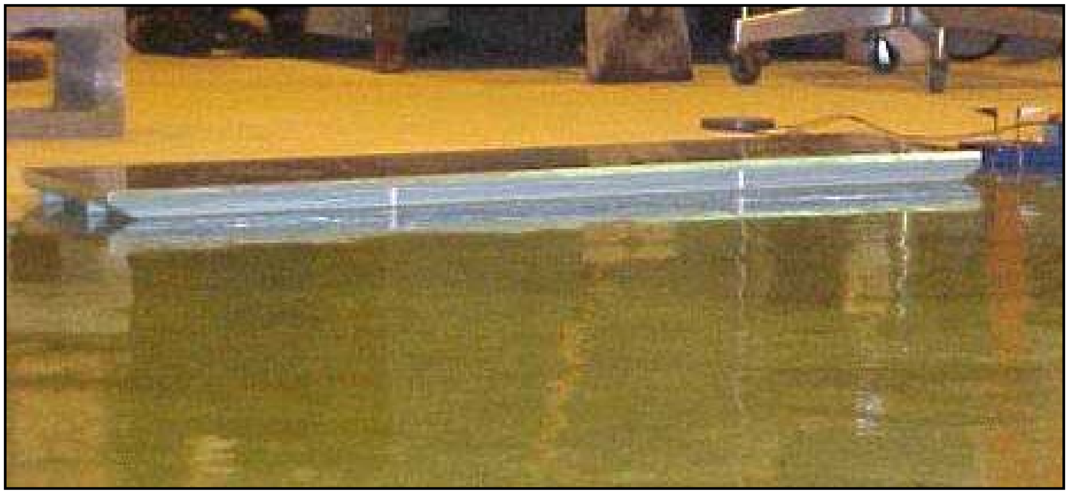


Figure 10. Model *Kukahi* oceangoing barge.

*Static calibration*

Each vessel was partitioned into three or more holds. Lead weights were distributed in these holds as ballast to obtain the desired draft of 39 ft for the two ships and 13.5 ft for the barge. All weights were numbered and weighed for easy identification. The empty *President Lincoln* weighed 86.18 lb without the cargo hold covers and 93.44 lb with these covers. The total ballast with the 12-volt battery was 206.99 lb. For the *Bunga Saga Empat*, the empty weight of the ship without cargo hold covers was 94.4 lb and 113.2 lb with the covers. The total ballast with the battery for this ship was 334.10 lb.

The static calibration procedure consisted of the following sequence of steps. First, the ships were placed in the water and the lead weights were installed in the proper order. Next, the draft of the vessels was checked at four locations: two on the port and two on the starboard sides at both bow and stern positions. To facilitate these measurements, vertical distance scales on the outside of the ships at these four locations were used. These four measured values were required to match each other within 0.08 in. Finally, an additional measurement was made for the two ships using a digital level, aligned bow to stern and port to starboard. These measurements insured that the correct set and trim were obtained for the vessels. Appendix A contains a listing of the weight distributions and digital level readings for each vessel. Photographs of the weight distributions are also contained in Appendix A.

*Dynamic calibration*

Dynamic calibration of both vessels had been performed in the previous studies (Briggs et al. 1994; Harkins and Dorrell 2000). After the static calibration was completed, the ships were displaced from their equilibrium positions and released. A stopwatch was used to time the natural periods in pitch and roll by counting the number of cycles before the motion stopped due to inherent damping in the water. Thus, the weight distributions used in this study were based on replication of those used in the previous two studies.

### MOTAN six degree of freedom motions

The six degree of freedom (6DOF) motions of a moving ship are the three translations of surge, sway, heave, and the three rotations of roll, pitch, and yaw (Figure 11). A ship typically rotates about the center of gravity (CG), located on the longitudinal centerline approximately amidships. The vertical portion of a ship's wave-induced motion consists of contributions from heave, pitch, and roll.

A Motion Analysis System (MOTAN) was used to record the 6DOF vessel motions of the model ships in this study. Figure 12 shows a typical installation of the MOTAN in the *President Lincoln* model vessel. Equivalent amounts of lead weights were removed to compensate for the weight of the MOTAN components. The inertial motion sensor unit contains three linear servo accelerometers and three micro-machined quartz angular rate sensors. The accelerometers measure the total acceleration along X, Y, and Z body axes of the ship model. The angular rate sensors measure angular rotation vectors of the model. The sensor unit is only 6 in. long, 6 in. wide, 4.5 in. high and weighs 3.43 lb. The data acquisition system uses a data logger to record the analog voltage signals from the six sensors. A sampling rate of 50 Hz was used to prevent aliasing of high frequency noise. Software allows the motions to be computed at the CG of a vessel or the bow of a vessel even if the sensor unit is installed at some other position.

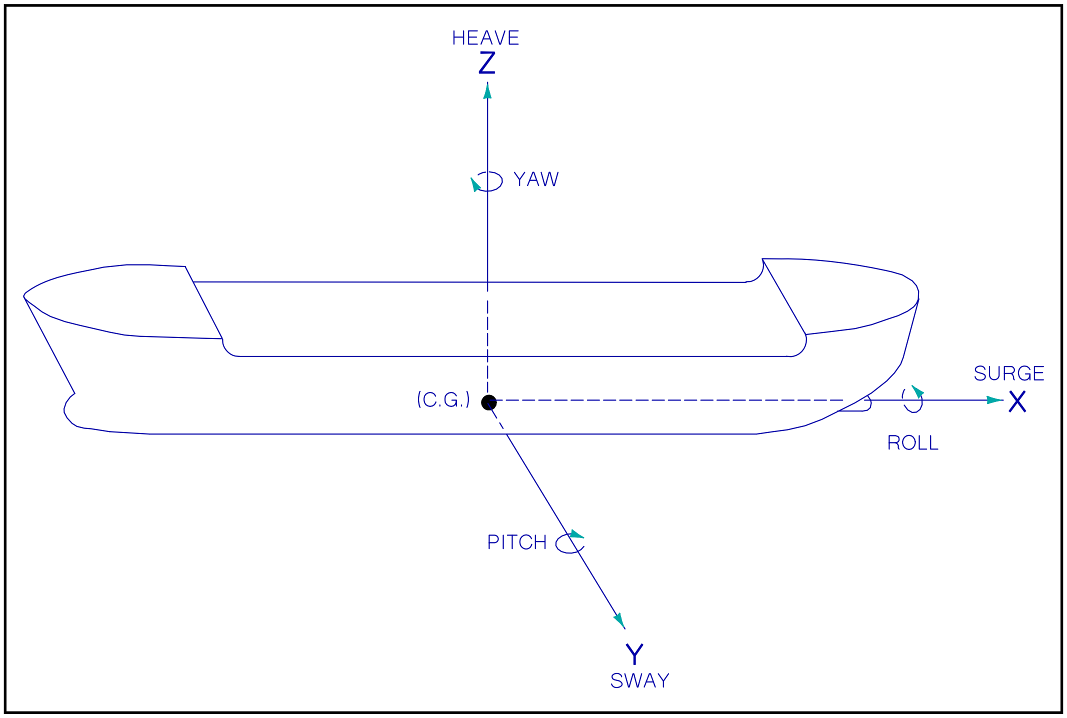



Figure 11. Six degree of freedom motions for a vessel.


Figure 12. Typical installation for MOTAN motion analysis system.

# 3 Procedure

The model study consisted of four phases: (a) calibration, (b) production, (c) pilot, and (d) optimization. Table 3 summarizes the jetty configuration, wave direction, run number, wave gage and current meter setups, vessel, number of test runs, and number of transits for each phase. Although there were four wave cases, some were repeated (usually the $T_p$ = 18 sec wave case) and some were not run at all (especially in the Pilot Phase). Thus, the number of test runs can be different than the number of wave cases.

## Calibration phase

In the Calibration Phase, seven capacitance wave gages were used to iteratively match target wave parameters. Four gages were located outside the channel and three gages were positioned along the length of the channel. Target wave parameters were calibrated at wave gage 2 outside the channel in the 32-ft water depth (similar to earlier laboratory studies). For the S80W wave direction, the four wave cases were calibrated with the no-jetty configuration. For the S25W wave direction, no attempt was made to recalibrate the control signals, although the waves were measured with the no-jetty, 225-ft, and 450-ft jetty lengths as baseline conditions. Several additional runs were conducted with two current meters for the no-jetty configuration. These current meters were positioned on the channel centerline at the projection of the no-jetty and the 450-ft-long jetty, with measurement volumes at mid-depth in the channel. Ship speed trials were conducted to calibrate ship speeds to the remote control settings. Target ship speeds were 5 kts.

## Production phase

In the Production Phase, the model *President Lincoln*, *Bunga Saga Empat*, and *Kukahi* made a total of 392 inbound and outbound transits. First, the S80W wave direction cases were studied for jetty lengths of 0, 225, and 450 ft. In general, each ship experienced four round trips for each wave condition and jetty length combination. The three channel wave gages were removed for this phase and data were collected with only the four remaining outside wave gages. Dye, overhead camera, and visual observations were used to monitor wave-induced current flows during

Table 3. Test plan summary.

| Jetty Length (ft) | Wave Direction | Run No. | Instruments: Wave | Instruments: Current | Vessel | Number of: Tests | Number of: Transits |
|---|---|---|---|---|---|---|---|
| Calibration Phase | | | | | | | |
| None | S80W | 5 | 7W1 | 2C1 | None | 4 | 0 |
| | | 6 | | | | 4 | |
| | S25W | 7 | | | | 4 | |
| 225 | | 8 | | | | 7 | |
| 450 | | 9 | | | | 8 | |
| Production Phase | | | | | | | |
| None | S80W | 12 | 4W1 | None | *APL* | 5 | 40 |
| | | 11 | | | *Bunga* | 5 | 39 |
| | | 13 | | | *Kukahi* | 4 | 32 |
| 225 | | 17 | | | *Bunga* | 4 | 32 |
| | | 19 | | | Kukahi | 4 | 32 |
| 450 | | 14 | | | *APL* | 4 | 32 |
| | | 15 | | | *Bunga* | 4 | 32 |
| | | 16 | | | Kukahi | 4 | 30 |
| None | S25W | 21 | | | *Bunga* | 4 | 32 |
| | | 27 | | | Kukahi | 4 | 32 |
| 450 | | 23 | | | *Bunga* | 4 | 32 |
| | | 29 | | | Kukahi | 4 | 27 |
| Pilot Phase | | | | | | | |
| None | S25W | N/A | None | None | *Bunga* | 1 | 4 |
| | | | | | Kukahi | 4 | 8 |
| 225 | | | | | None | 4 | 0 |
| 300 | | | | | None | 1 | 0 |
| 375 | | | | | None | 2 | 0 |
| 450 | | | | | *Bunga* | 1 | 4 |
| | | | | | Kukahi | 1 | 4 |
| 225S | | | | | Bunga | 3 | 6 |
| 450S | | | | | *Bunga* | 4 | 8 |
| Optimization Phase | | | | | | | |
| None | S25W | 35 | 7W2 | 4C2 | None | 4 | 0 |
| 375 | | 34 | | | | | |
| | | 44 | | | | | |
| 400 | | 33 | | | | | |
| | | 43 | | | | | |
| 425 | | 32 | | | | | |
| | | 42 | | | | | |
| 450 | | 31 | | | | | |
| | | 41 | | | | | |
| | | | | | Totals: | 135 | 426 |

Notes:
1. 7W1 = First wave gage setup with 7 gages.
2. 4W1 = First wave gage setup with 4 gages, 3 channel gages removed.
3. 7W2 = Second wave gage setup with 7 gages.
4. 2C1 = First current meter setup with 2 meters.
5. 4C2 = Second current meter setup with 4 meters.
6. 225S and 450S = Jetty placed on south side of channel.

these ship transits. Next, the wavemaker was repositioned to generate the S25W waves. A total of 123 transits were made with the *Bunga Saga Empat* and the *Kukahi* for the no-jetty and 450-ft jetty configurations. Data were collected with the four wave gages. Qualitative measurements were made with the dye, overhead camera, and visual observations.

### Pilot phase

In the Pilot Phase (Progress Review Meeting), the harbor pilots assisted in the conduct of experiments with all three vessels for S25W waves. In addition to jetty lengths of 0, 225, 300, 375, and 450 ft on the north side of the channel, two jetty lengths (225 ft and 450 ft) on the south side were also investigated. Dye was used to visualize the current patterns. Participating in and witnessing these tests were Stan Boc, HED; Dr. Wendy I. Wiltse, EPA; Capt. Dave Lyman, HPA; Capt. Thomas L. Heberle, HPA; and Capt. Warren B. Ditch, Jr., Hawaiian Tug and Barge.

### Optimization phase

Based on the results from the Pilot Phase, a minimum length of at least 375 ft was felt to provide needed navigation safety. This conclusion was a compromise between safe navigation considerations, pilot observations of ship handling, and environmental concerns. The purpose of the optimization phase was to further optimize the jetty length by studying the current magnitudes in the entrance channel for four different jetty lengths: 375, 400, 425, and 450 ft. Previously, only jetty lengths of 225, 300, 375, and 450 ft had been studied. Four current meters were placed, one every 50 ft along the channel centerline, at locations corresponding to jetty lengths of 300 to 450 ft. Wave data were recorded at seven locations (wave gage setup 2): (a) three outside the channel to measure incident wave conditions, (b) three along the channel centerline at locations of 0, 225, and 525 ft relative to the jetty origin, and (c) one in the north corner of the barge basin (similar to the Briggs et al. 1992 study). The same four wave cases from the S25W wave direction were used. Two repeat runs were made with each wave. No additional navigation tests were conducted in this phase of the study.

# 4 Model Calibration

## Wave environment

### Wave selection

Waves typically approach Barbers Point Harbor from the northwest and southwest. Waves approach from the west only during Kona (local) storms. The island of Oahu blocks out easterly trade-wind waves. The largest waves occur during the winter and are due to northerly swell from the Northwest Pacific.

A comprehensive set of wave data from July 1986 to March 1990 for offshore and harbor locations (Lillycrop et al. 1993) was collected under the Monitoring Completed Navigation Projects Program. These data provided a realistic range of wave conditions that were used in the previous studies by Briggs et al. (1994) and Harkins and Dorrell (2000). A wave height of 7 ft was selected by Harkins and Dorrell (2000) and in this study as a reasonable value during which harbor pilots would be willing to bring a vessel into the harbor. Since the vessel's response is a function of wave parameters, a total of eight wave conditions were selected for study. Model unidirectional spectral waves were simulated for waves with wave periods of 6, 10, 14, and 18 sec, wave height of 7 ft, and incident wave directions of S80W deg (west or 35 deg west of the channel centerline) and S25W deg (southwest or 20 deg south of the channel centerline). These wave conditions corresponded to those used in the two previous studies by Briggs et al. (1994) and Harkins and Dorrell (2000). Since the channel centerline is aligned with S45W, these wave directions provided roll and pitch forcing within the range of previously studied wave directions from S22W (23 deg south of the channel centerline) to N78W (57 deg west of the channel centerline). Most of the tests were conducted for the second wave direction.

### Wave calibration

Prior to calibrating the waves, static and dynamic calibrations were run for the unidirectional, plunger wavemaker. The static calibration drives the wave machine between minimum and maximum voltage (i.e., ±10 volts), to measure the wave board displacements for full forward and full reverse strokes. The dynamic calibration creates a swept sine wave with slowly increasing frequency and slowly decreasing amplitude between initial and maximum frequencies (i.e., 0.1 Hz and 3.0 Hz). The GEDAP (Miles 1997) software was used to generate and analyze the control signals.

Unidirectional wave spectra were generated for each wave condition. Input parameters include the wave height $H_{m0}$, peak wave period $T_p$, water depth $h$, Phillip's constant $\alpha$, and the peak enhancement factor $\gamma$. The peak enhancement factor controls the peakedness of the spectrum and typically varies between 1 to 3.3 for sea conditions and 7 and higher for swell waves. Both $\alpha$ and $\gamma$ influence the energy contained in the wave spectrum. A time series of 1,200 sec duration was created for each wave case. Figure 13 illustrates the shapes of the wave spectra for the four wave periods.

Surface wave elevation data were sampled at 10 Hz (i.e., $\Delta t = 0.10$ sec) for 20 minutes (i.e., 12,000 points). The wavemaker has a built in 10-sec ramp to prevent damage to the waveboard when the control signals are first started. Also, high frequency components in the wave train travel slower and require a longer time to reach the farthest gages in the model. Thus, the first 50 sec of the recorded data were skipped and only 1,000 sec of the records were analyzed (i.e., 50 to 1,050 sec).

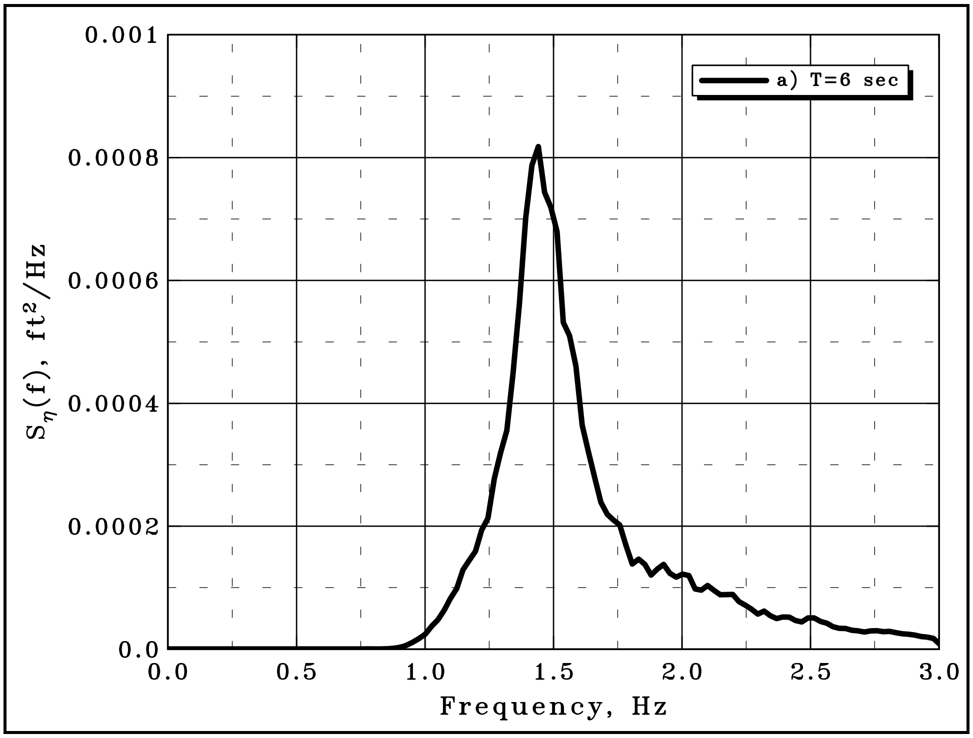
The waves were originally calibrated for the S80W wave direction. An iterative procedure was followed for generating, measuring, and correcting the control signals to match the target wave parameters. At least four runs were made to achieve the final calibration for each wave case. Table 4 lists target and measured wave heights ($H_{m0}$ values) and peak wave periods $T_p$ at the incident gage 2 for each of the eight wave cases. After several iterations, the agreement between the measured and target wave conditions was very good, although the wave heights were a little low for the $T_p$= 14 sec case. The final gain factors were 66.6, 80.7, 77.6, and 75.2 percent for $T_p$ = 6, 10, 14, and 18 sec, respectively.

After the wavemaker was moved to the second location at S25W, additional calibration runs were made to verify that the target wave parameters were still being met. However, no attempt was made to correct the waves after this move to compensate for any differences in the channel due to wave processes such as diffraction and refraction.

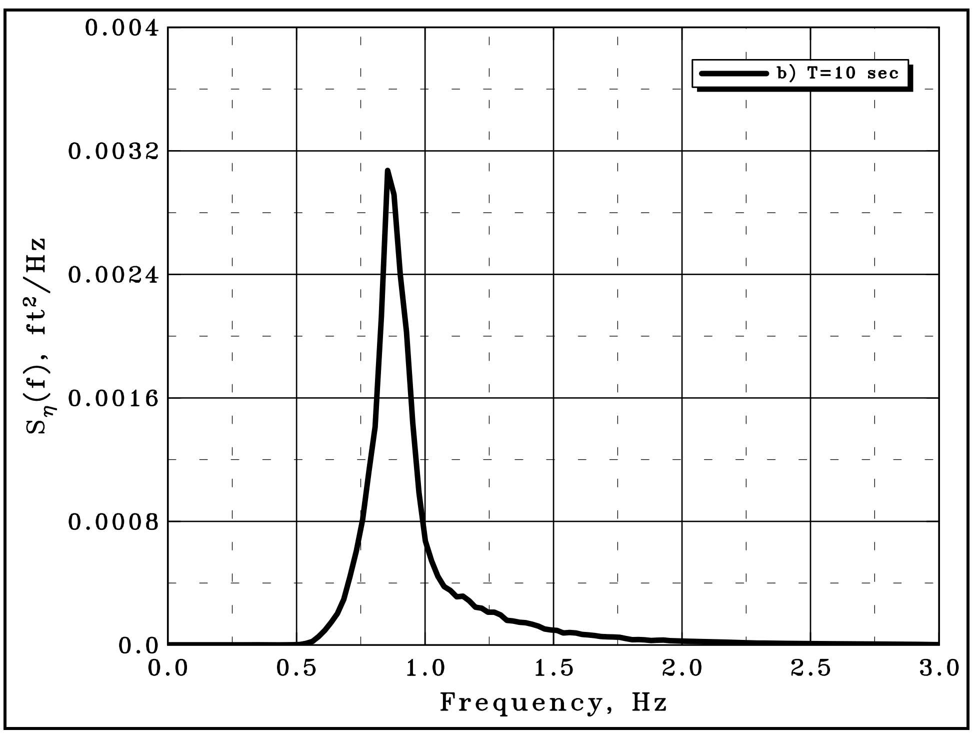
Figures 14a and 14b show the measured wave heights for the seven wave gages in the first gage setup for each of the two wave directions and the no-jetty configuration. The corresponding peak wave periods are shown in Figures 15a and 15b. Gage 2 was the main gage used for calibration of the control signals. The effect of the jetty length was negligible on the measured wave parameters for all wave cases. Figure 16 shows the wave height variation for the $T_p$= 6 sec case which was typical for all wave cases. Appendix B contains listings of the measured wave heights and periods during the Calibration Phase.

Table 4. Target versus measured wave parameters.

| Case | Target | | | S80W Waves | | | S25W Waves | | |
|---|---|---|---|---|---|---|---|---|---|
| | $T_p$ (sec) | $H_{m0}$ (ft) | γ | ID | $T_p$ (sec) | $H_{m0}$ (ft) | ID | $T_p$ (sec) | $H_{m0}$ (ft) |
| BPJ09 | 6 | 7 | 3.3 | 306 | 6.0 | 7.1 | 207 | 5.9 | 7.1 |
| BPJ10 | 10 | 7 | 5.0 | 306 | 9.9 | 7.0 | 207 | 10.1 | 7.6 |
| BPJ11 | 14 | 7 | 7.0 | 306 | 14.2 | 6.7 | 207 | 14.2 | 6.1 |
| BPJ12 | 18 | 7 | 10.0 | 306 | 16.9 | 7.0 | 207 | 17.7 | 7.2 |

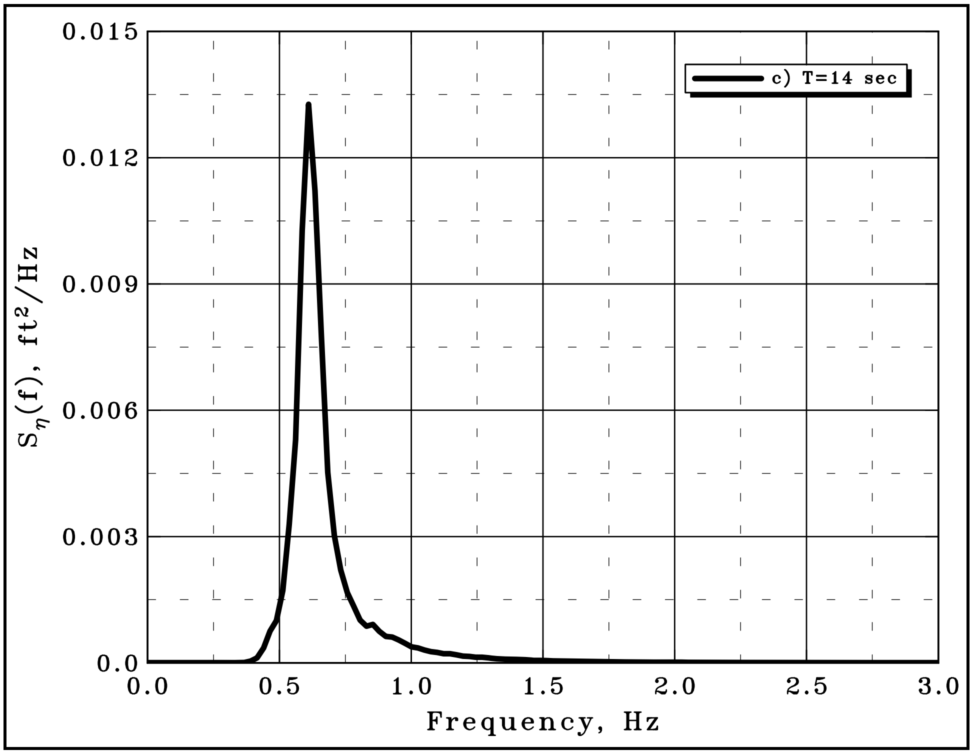



(a) $T_P$=6 sec wave case.

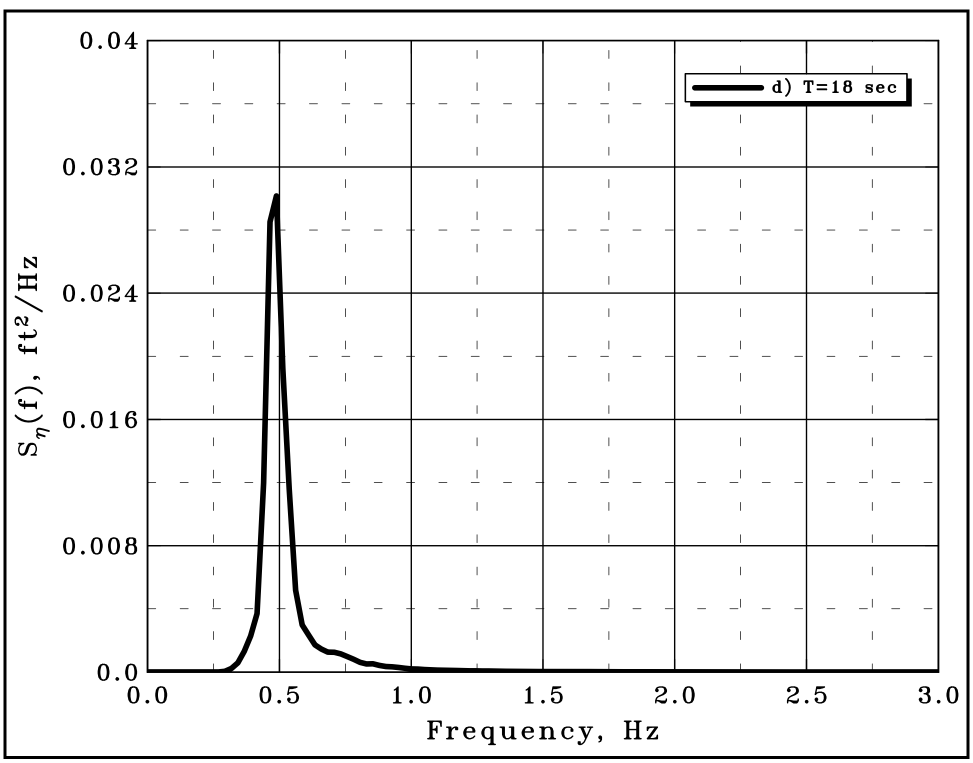



(b) $T_P$=10 sec wave case.

Figure 13. Target spectral shapes for four wave cases (Continued).

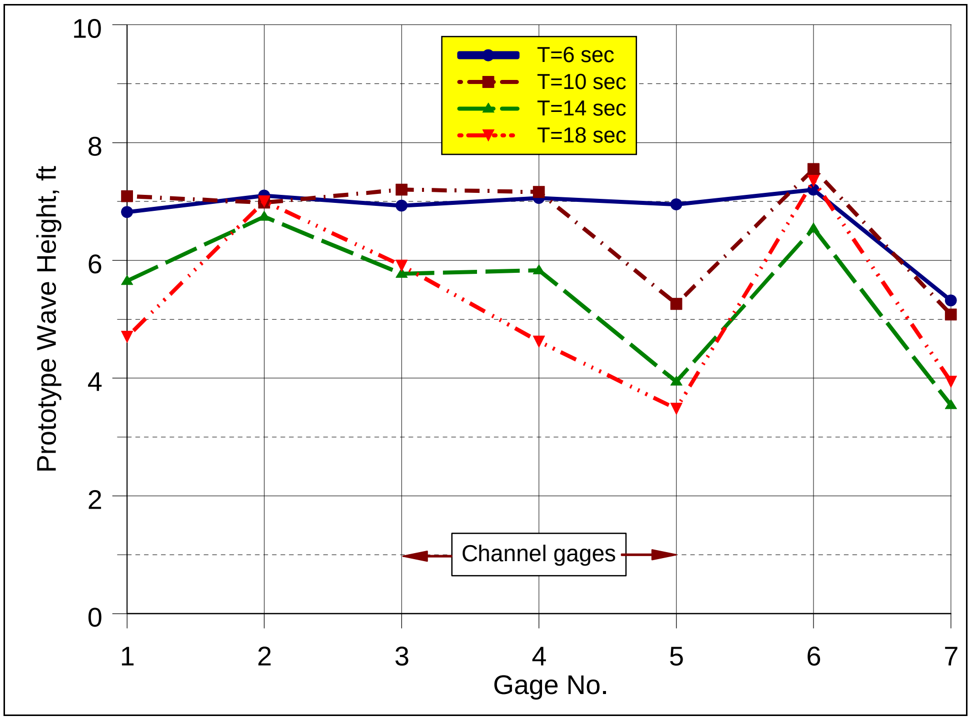



(c) $T_P$ =14 sec wave case.

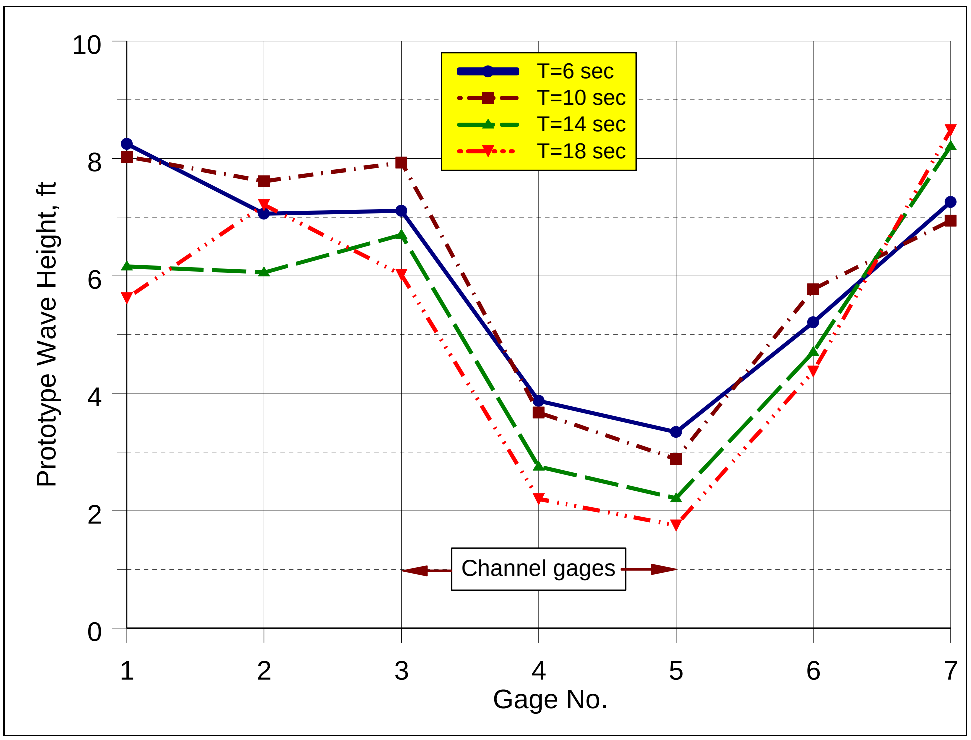



(d) $T_P$ =18 sec wave case.

Figure 13. (Concluded).

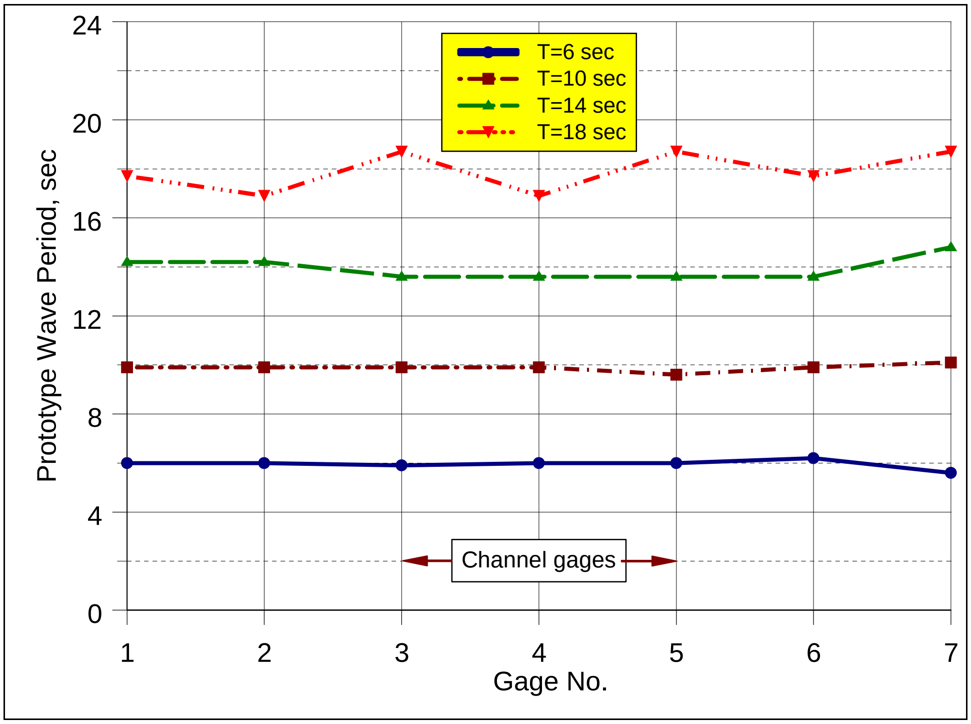



(a) Wave direction S80W (i.e., 35 deg west of channel centerline).

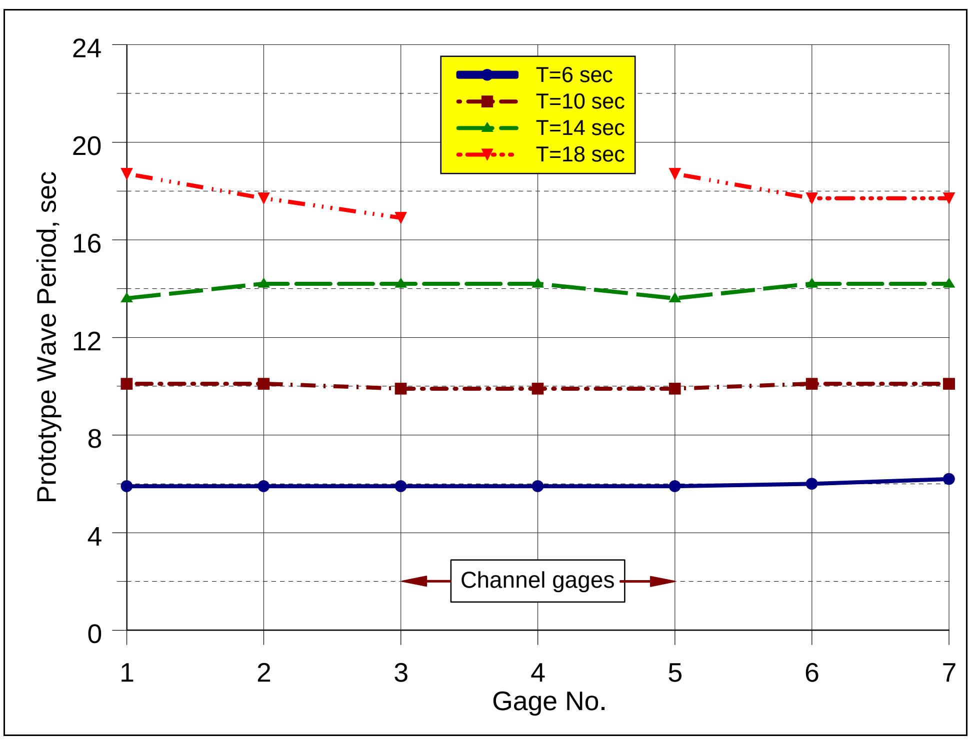



(b) Wave direction S25W (i.e., 20 deg south of channel centerline).

Figure 14. Measured wave heights for no-jetty configuration, Calibration Phase.




(a) Wave direction S80W (i.e., 35 deg west of channel centerline).




(b) Wave direction S25W (i.e., 20 deg south of channel centerline).

Figure 15. Measured peak wave periods for no-jetty configuration, Calibration Phase.

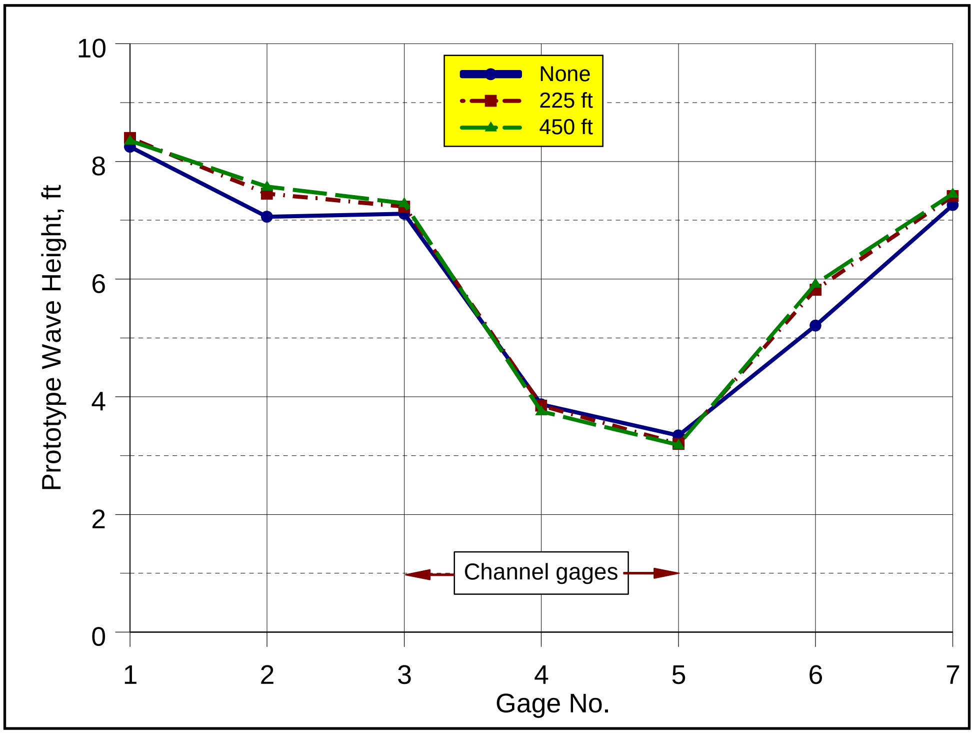



Figure 16. Effect of jetty length on measured wave heights with $T_p$ = 6 sec, S25W wave direction, Calibration Phase.

## Ship speed trials

Prior to conducting any tests, a series of speed trials were conducted to calibrate the remote control tachometers with the appropriate ship speeds. The tachometers have discrete click stops rather than a continuous range of speed control. Therefore, it was not possible to set exact speeds, and speed trials were necessary to calibrate the tachometer for each ship and transit direction in still water.

The length of the channel used in the speed trials was 3,750 ft, between an offshore start/stop line near station 3 and an inshore start/stop line near station 40. Stopwatches were used to measure the travel time between these start/stop lines using the passage of the ship's stern for inbound transits and ship's bow for outbound transits. Based on previous model studies for Barbers Point Harbor (Briggs et al. 1994; Harkins and Dorrell 2000), a target speed of 5 kts was selected for inbound and outbound transits for the two ships. The target speed for the *Kukahi* barge tow by the *World Utility* was 4 kts.

For each ship transit direction, four to six different tachometer settings were selected to bracket the target speed. In addition, at least one repeat run was made for each transit. The target tachometer setting (i.e., number of click stops) corresponding to the target speed was then estimated using a least squares quadratic fit of the data for each ship. Table 5 lists these calibration coefficients for each vessel. Figure 17 shows the measured and fit ship speed versus tachometer setting. In general, the fit was excellent with the square of the correlation coefficient ranging from 0.95 to 1.00. Appendix C lists the vessel speeds and tachometer settings for inbound and outbound transits for the two ships and the barge tow.

Table 5. Speed trial calibration results.

| | | Coefficients | | | |
|---|---|---|---|---|---|
| Ship | Direction | a | B * x | C * $x^2$ | $R^2$ |
| *President Lincoln* | Inbound | -5.9378 | 3.5896 | -0.1755 | 0.99 |
| | Outbound | -5.2671 | 3.3427 | -0.173 | 0.95 |
| *Bunga Saga Empat* | Inbound | -0.3045 | 2.5057 | -0.0761 | 1.00 |
| | Outbound | -1.253 | 2.8141 | -0.1398 | 0.99 |
| *Kukahi* barge (Maximum draft) | Inbound | -1.2068 | 1.1502 | -0.0177 | 1.00 |
| | Outbound | -0.3611 | 0.9489 | -0.0088 | 0.99 |

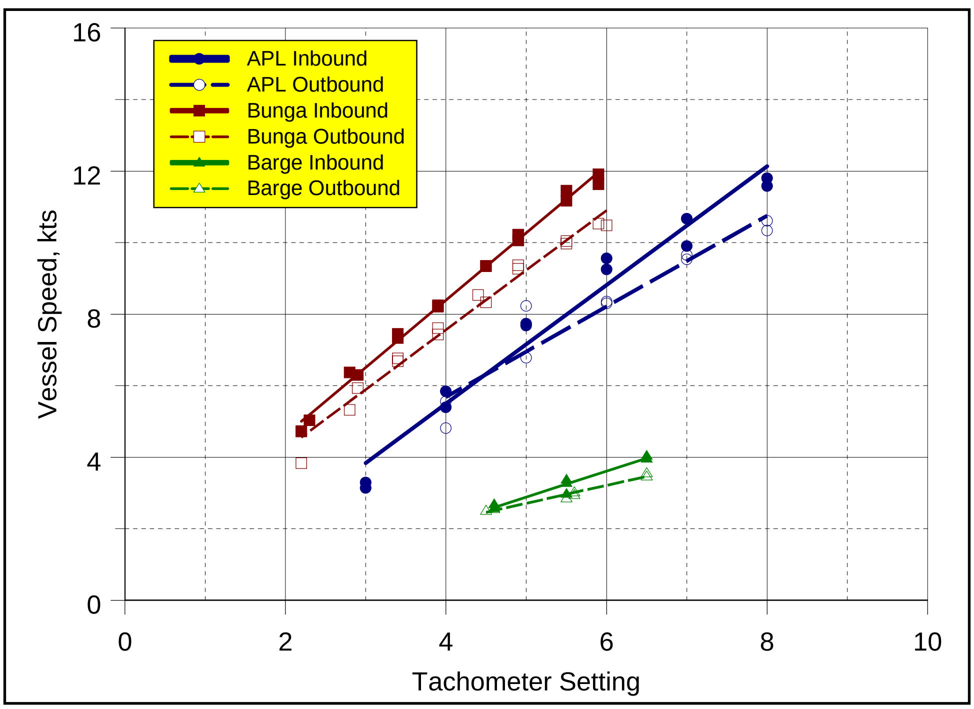



Figure 17. Vessel speed calibration.

# 5 Results

This section contains a summary of the results on wave heights, ship response, circulation and current patterns, and sponsor and pilot input.

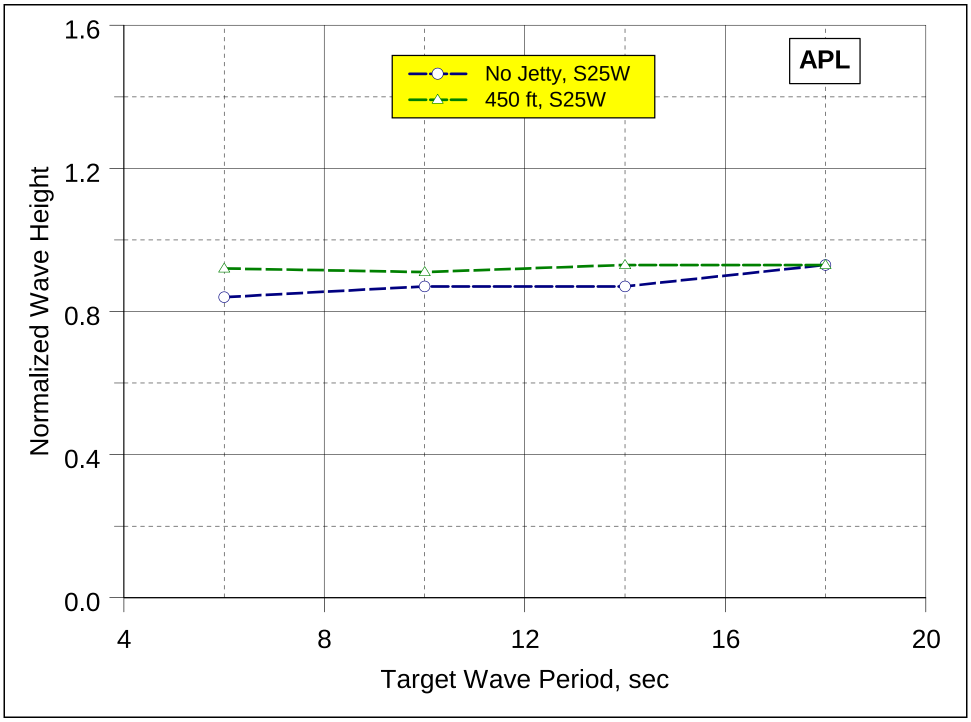
## Wave height comparisons

This section examines the effect of the jetty on the measured wave heights in the model. The first wave gage setup was used in the Production Phase. It is important that the heights used during these tests remain consistent without any significant changes from those obtained in the Calibration Phase. In the Optimization Phase, the second wave gage setup was used. The concern here is to make sure the jetty lengths do not adversely impact the wave environment in the vicinity of the jetty.

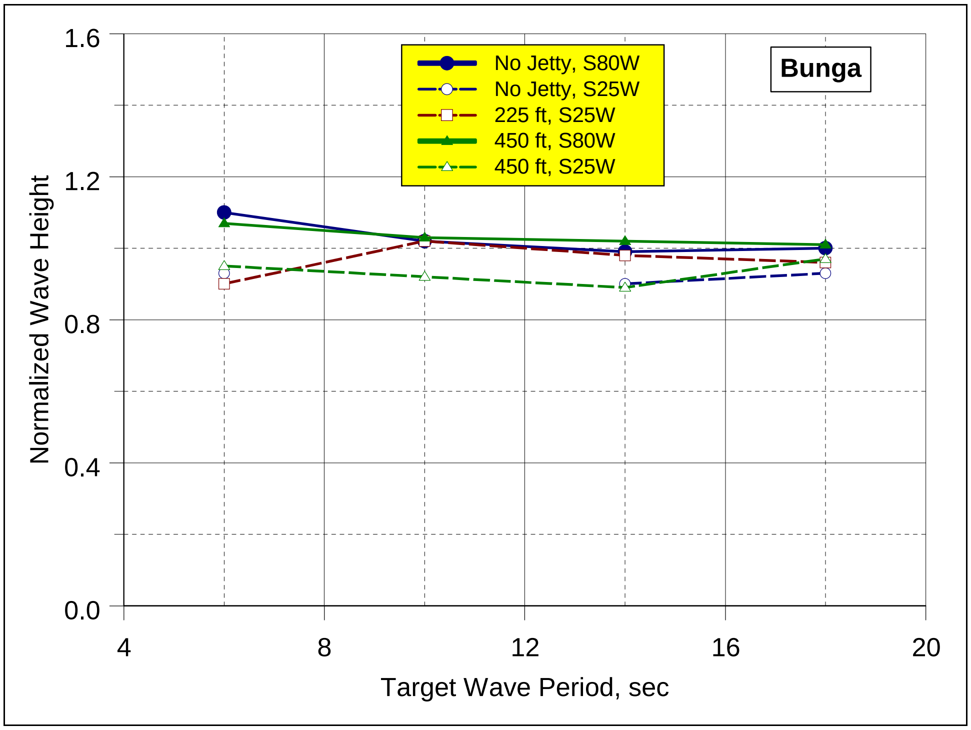
### Production phase

Figure 18 shows the normalized incident wave height at gage 2 versus target wave period for the three vessels during the Production Phase. Closed symbols are used for the S80W wave direction cases and open symbols for the S25W wave direction. Blue, red, and green colors represent the no-jetty, 225-ft-long, and 450-ft-long configurations, respectively. Not all jetty configurations and wave conditions were tested for each vessel.

In general, the data oscillate about a value of 1.0, indicative that the incident waves during the Production Phase were similar to those obtained in the Calibration Phase. Table 6 lists the measured incident wave heights from the Calibration Phase used in the normalization. Tabular listings of the normalized and measured wave heights during the Production Phase are contained in Appendix D. Measured wave periods are also listed in Appendix D. There was very little change in the wave periods during the different tests.

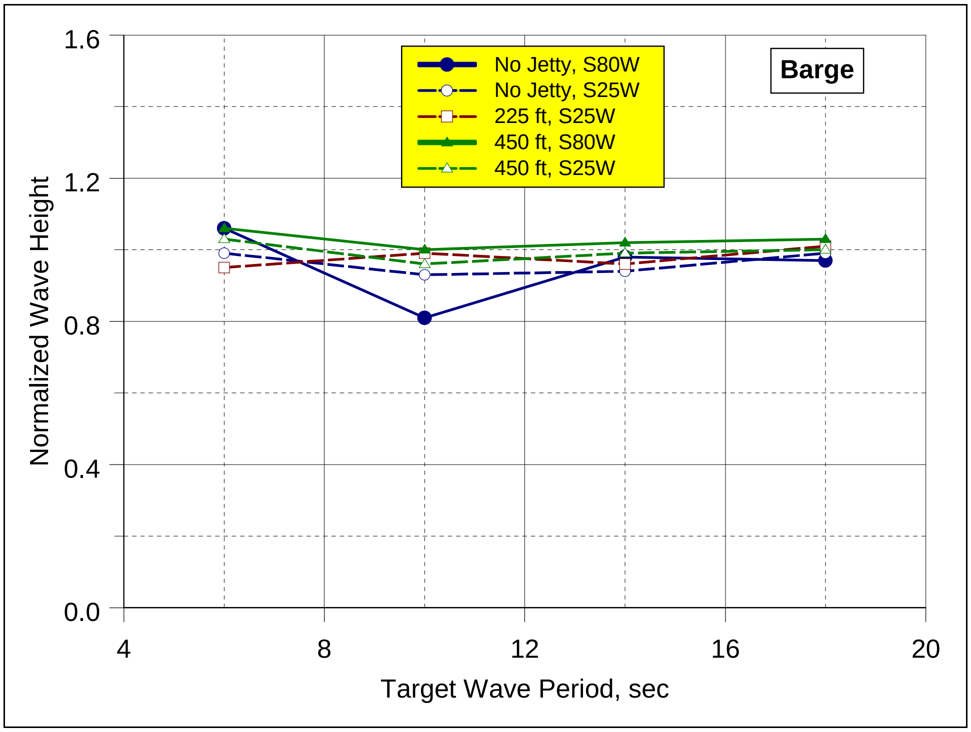



(a) *President Lincoln* transits for S25W wave direction.




(b) *Bunga Saga Empat* for S80W and S25W wave directions.

Figure 18. Normalized wave heights during Production Phase (Continued).




(c) *Kukahi* barge for S80W and S25W wave directions.

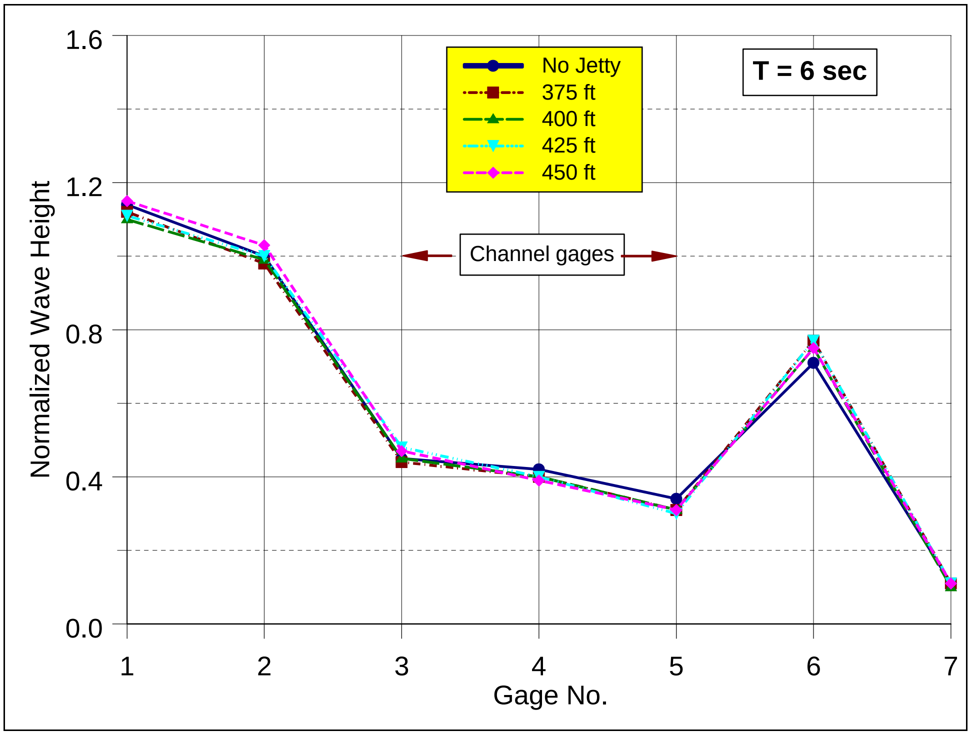
Figure 18. (Concluded).

Table 6. Wave height normalizing constants from Calibration Phase.

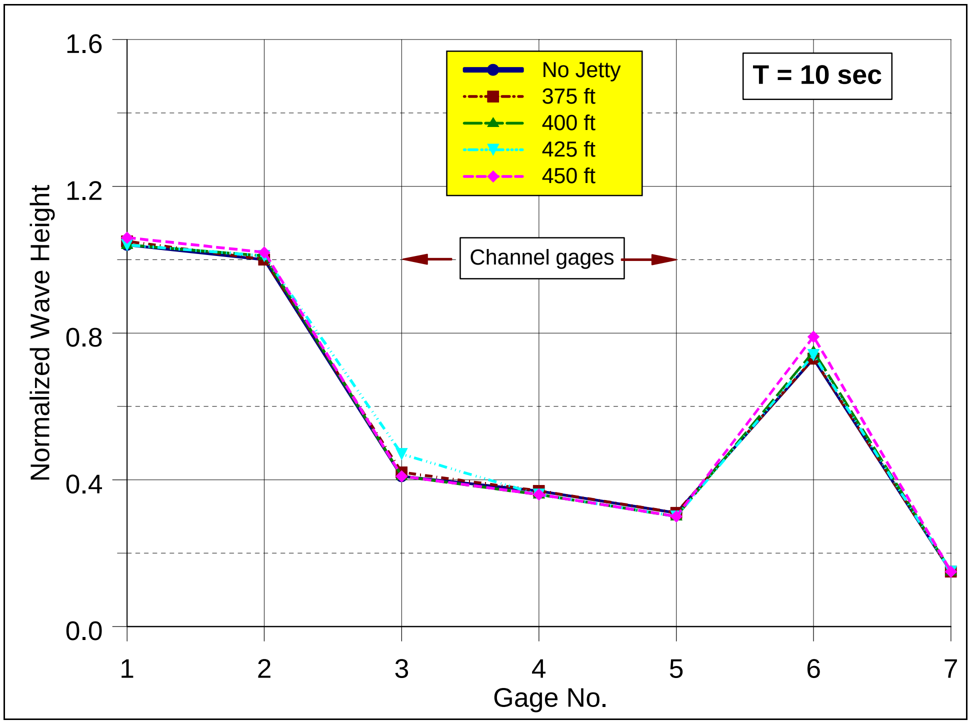
| Case ID | Wave Period, sec | Wave Direction | |
|---|---|---|---|
| | | S80W | S25W |
| BPJ09 | 6 | 7.10 | 7.06 |
| BPJ10 | 10 | 6.98 | 7.61 |
| BPJ11 | 14 | 6.74 | 6.06 |
| BPJ12 | 18 | 7.00 | 7.21 |

## Optimization phase

Figure 19 shows the normalized wave heights for the second wave gage setup for each of the four wave cases. The average wave height for each gage was obtained by averaging both runs. This average wave height was then normalized by the no-jetty (Run 35) wave height at gage 2. The normalizing wave height constants are 7.4, 7.8, 6.3, and 7.3 for the four wave periods, respectively, for wave heights in feet. These comparisons illustrate relative wave heights at the different locations inside the channel and in the barge basin.

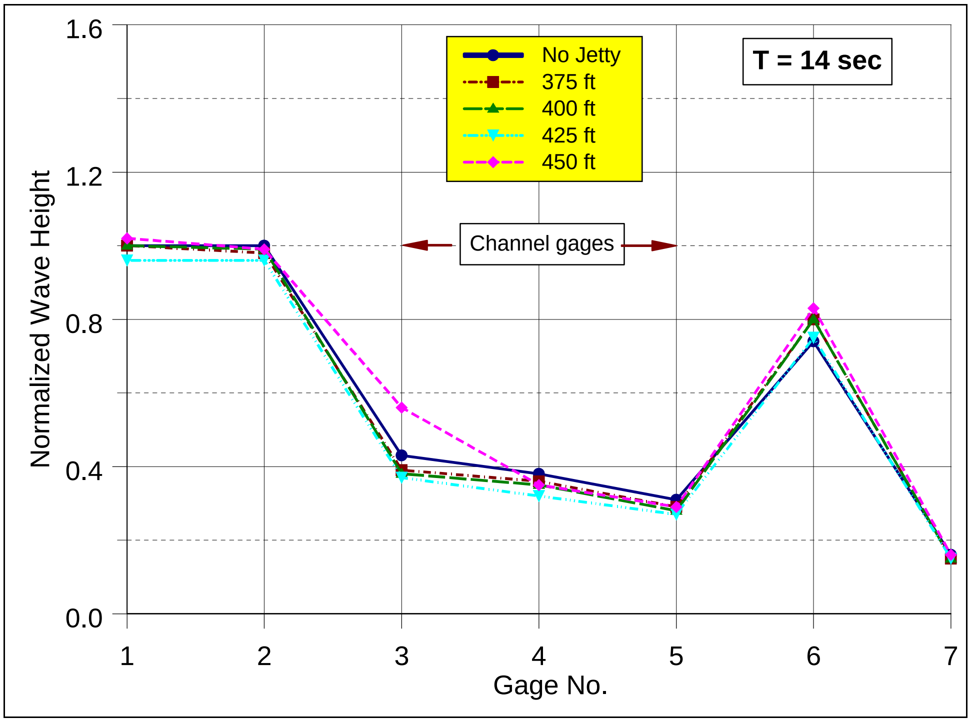



(a) $T_p$ = 6 sec wave cases.

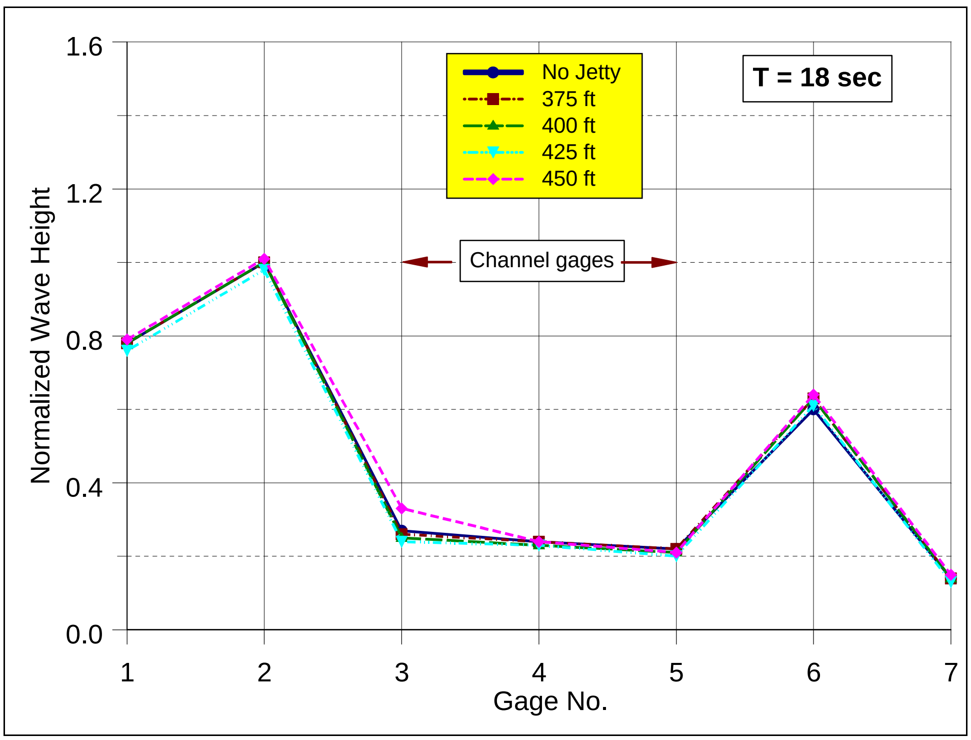



(b) $T_p$ = 10 sec wave cases.

Figure 19. Normalized wave heights during Optimization Phase (Continued).




(c) $T_p$ = 14 sec wave cases.




(d) $T_p$ = 18 sec wave cases.

Figure 19. (Concluded).

Gage 2 is the incident gage that was used in the calibration of the wave control signals. The original target wave heights were 7 ft for waves from S80W. The average measured incident wave heights ranged from about 6.3 ft to about 8 ft.

Although the three channel gages are in a constant water depth, they do experience some wave transformation due to the changing water depths outside the channel and the channel sides. As expected, there were some variations in the measured wave heights in the channel as a function of peak wave period and wave direction. As wave period increases, wave height tends to decrease for locations closer to shore (gages 4 and 5). Also, the reduction in wave height is slightly greater for the waves from S25W. In general, there were only small differences in the measured wave heights in the channel due to changes in the jetty lengths for waves from S25W. The worst case was for the 450-ft-long jetty at gage 3, where a small increase in wave height was measured. Thus, a change in the jetty length will not significantly modify the wave height in the channel.

Gage 7 is in the north corner of the barge basin. In general, there are no significant differences in the measured wave height in the barge basin due to jetty length, with an average value near 1 ft.

Tabular listings of measured wave heights, normalized wave heights, and measured peak wave periods are given in Appendix E.

## Circulation and current patterns

This section examines the effect of the proposed jetty on the measured wave-induced longshore and cross-shore currents in the model. Flow patterns due to wave-induced longshore currents in the vicinity of the proposed jetty are very complex due to the bathymetry and the channel proximity. The harbor pilots have long observed crosscurrents in the channel near the shoreline that tend to yaw the vessels as they approach the harbor entrance.

The objective of these current measurements is to show that the proposed jetty will not have any adverse impacts on the existing current patterns with no-jetty. The earlier study by Briggs et al. (1994) recommended the 450-ft-long jetty to provide shelter from the crosscurrents with the existing depth transition. Now with the newly proposed depth transition and location, the goal is still to minimize the crosscurrents to provide safe navigation while minimizing any changes to the overall water circulation.

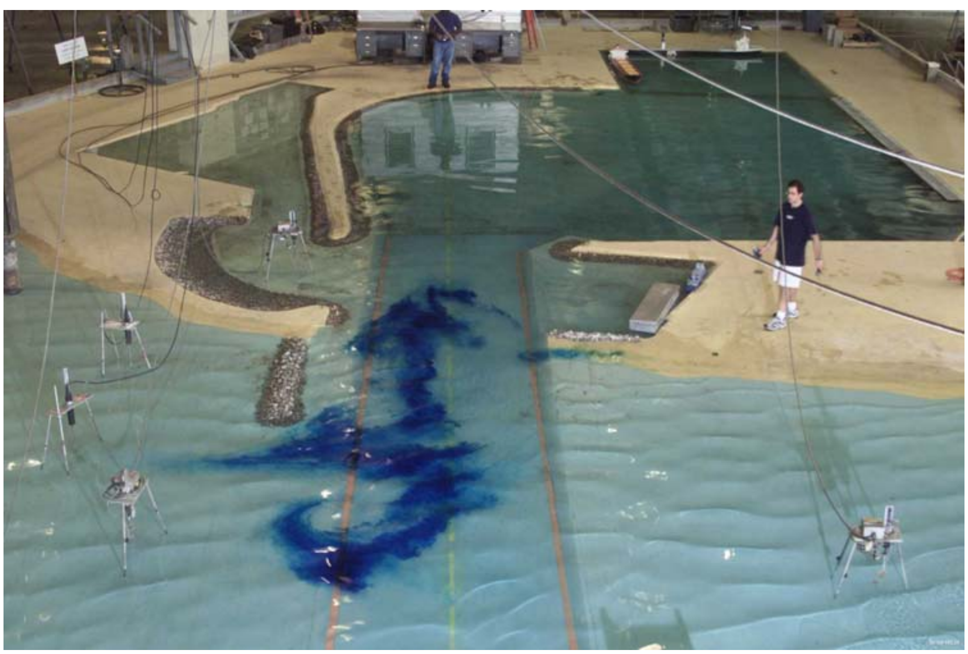
### Flow patterns

Figure 20 is a sequence of photographs showing the *Bunga Saga Empat* entering the harbor with the 450-ft-long jetty and $T_p$ = 6 sec waves from S25W. Note the complex shapes of the wave and current patterns due to refraction, diffraction, and reflection. The jetty does not appear to cause any dead zones in the overall circulation. The jetty tends to provide a more uniform flow (relative to no-jetty configuration) in the channel with the flow being diverted seaward beyond the jetty tip before it continues its movement up the coast. The seaward flow is confined mainly to the offset distance between the jetty and the channel side. The flow and circulation patterns for the other wave periods are similar for this wave direction. Appendix F contains photographs illustrating the base wave and currents for the no-jetty configuration for all wave periods.

Table 7 gives a summary of the overall current patterns for all wave period, wave direction, and jetty configurations. The ranges in this table represent distances measured offshore from the shoreline. The flow is generally to the west (see Figure 20). For instance, W0-225 represents flow to the west in the range from 0 to 225 ft and W0+ represents flow to the west from 0 ft offshore. The first example corresponds to a flow with a shear or reversal near 225 ft from the shore and the second example is a more uniform flow to the west from the shoreline offshore. These crosscurrents or shears occur at different locations along the channel. They are characterized by flow in the opposite direction or by slower flow in the same direction. Also, there are circulation cells in the channel that change direction and shape with time. Many have a classic “S” shape and others are more linear when looking down from above. The flow offshore along the jetty toe when a jetty is in place is denoted by S0+ in the table.

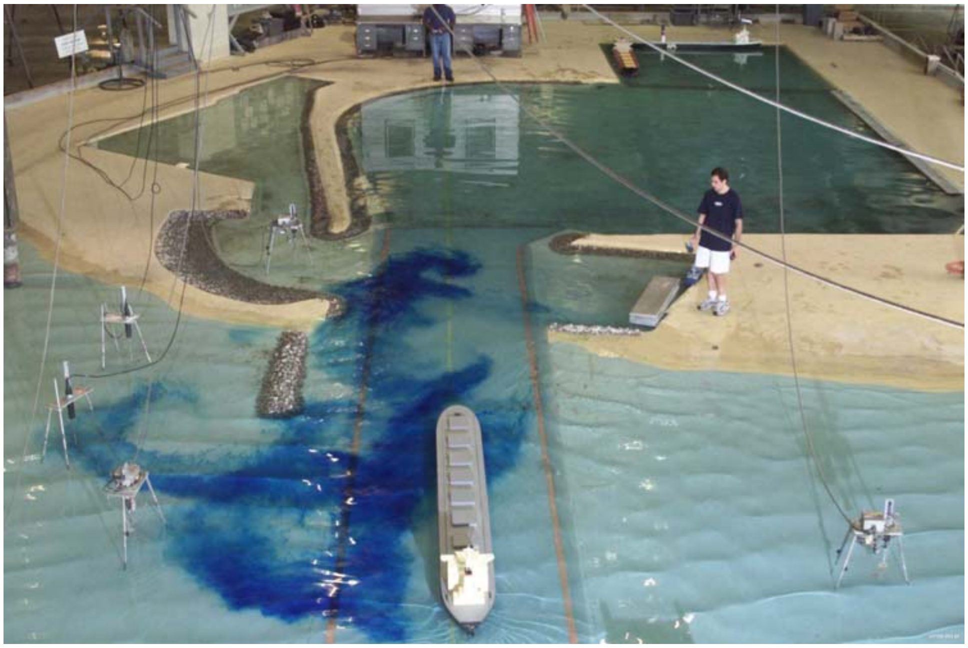
In general, the longshore current flows across the channel toward the proposed jetty site (or to the west) on the north side of the entrance channel. This is true for both wave directions tested in this study. The dominant mechanisms are wave refraction from the bottom contours, diffraction from the channel sides, reflection from the shore, and focusing by the shoreline orientation. In the region close to shore near the proposed jetty, the S80W waves are nearly normal to the shore and thus turned back to the north in a circulation cell. The S25W waves have an angle to the shoreline that naturally induces a longshore current to the west.

(a) Dye started on channel centerline; note shears in flow to west.



(b) Flow continues to west and begins flow around jetty tip.

Figure 20. Complex flow patterns of wave-induced longshore currents for $T_p$ = 6 sec wave case, S25W wave direction (Continued).


(c) Current flow is mainly to west, curling around jetty.

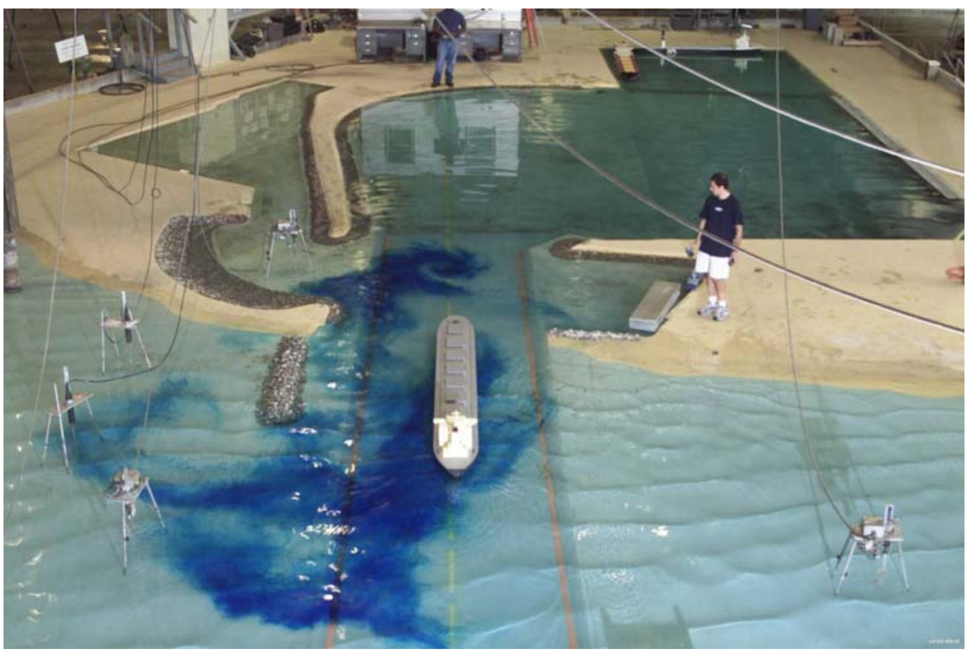

(d) Current flow continues to west with some eddies and vortices evident from the current shears in the channel.

Figure 20. (Concluded).

Table 7. Wave-induced longshore current summary.

| Jetty Length, ft | Peak Wave Period, sec | | | |
|---|---|---|---|---|
| | 6 | 10 | 14 | 18 |
| S80W Wave Direction | | | | |
| None | W0-225, E225+ | W0-225, E225+ | W0-225, E225+ | W0-450, E450+ |
| 225 | W0-225, E225-450, W450+ | W0-225, E225-300, W300+ | W0-225, E225+ | W0-225, E225-350, W350+ |
| 450 | W0-250, E250+ | W0-250, E250+ | W0+ | W0-225, E225-350, W350+ |
| S25W Wave Direction | | | | |
| None | W0-225, W225+, S0+ | W0-225, W225+ | W0+, W225-300, S225+ | W0+, S0+, |
| 225 | W0-225, W225+ | W0-225, W225+ | W0-225, W225+ | W0-225, W225+ |
| 300 | | | | |
| 375 | W0+, S0+ | | | W0+ |
| 450 | W0-225, E225-300, W300+, S0+ | W0+, S0+ | W0-225, W225+, S0+ | W0+, S0+, |
| S25W Wave Direction – Jetty on South Side of Channel | | | | |
| South 225 | W0+, W225+ | | W0+, W225+ | W0+, W225+ |
| South 450 | W0+, W450+ | W0+, W450+ | W0+, W450+ | W0+, W450+ |
| Notes:<br>W = flow predominantly to west, toward jetty in this range<br>E = flow predominantly to east, away from jetty in this range<br>S = flow predominantly to south, along jetty in this range | | | | |

### Current vector plots

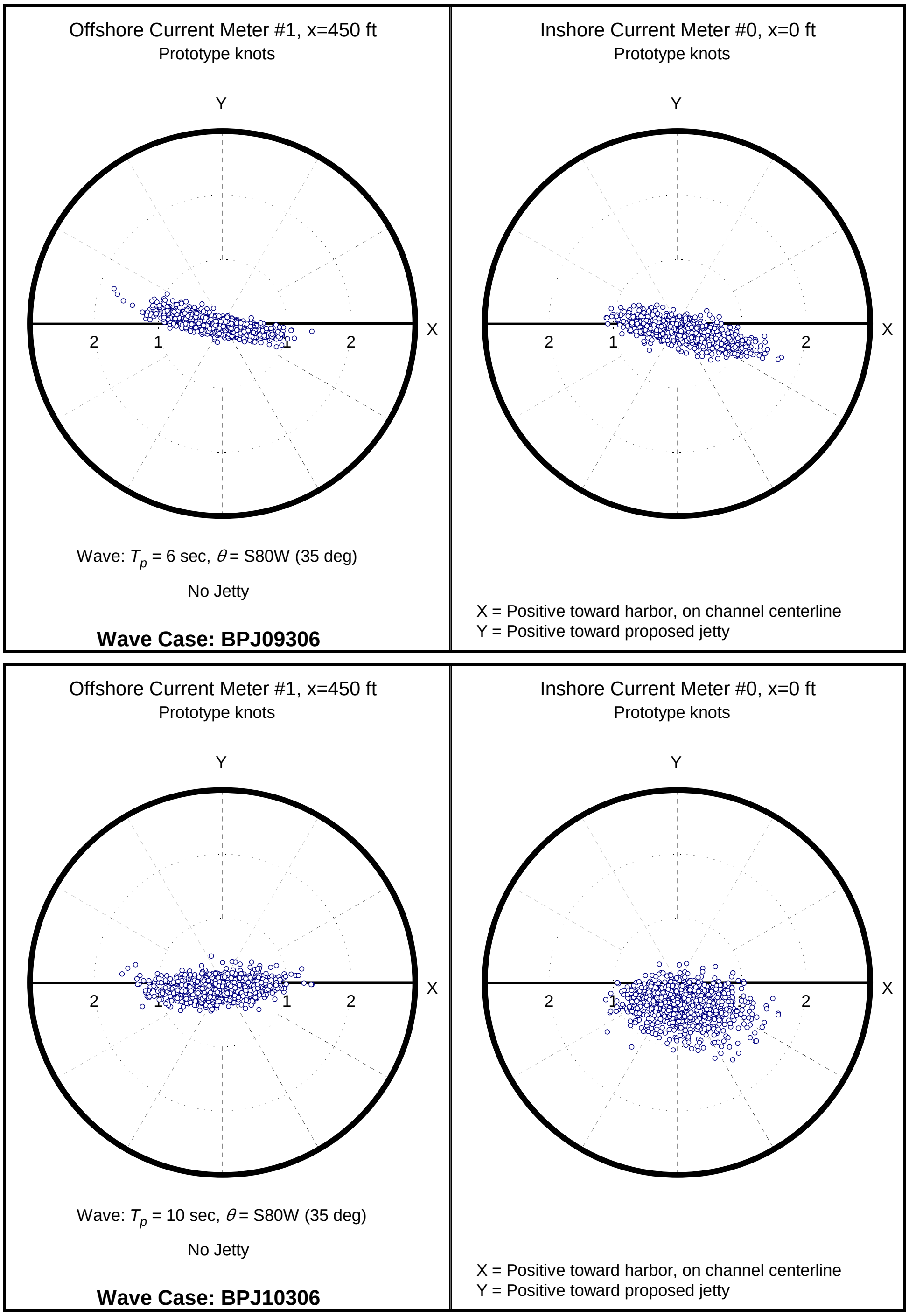
The *u*- (i.e., *x*-axis) and *v*-components (i.e., *y*-axis) of the measured currents were combined to obtain current vectors consisting of magnitude and phase. These were plotted as polar plots of the current vectors for each of the wave cases. Positive current direction is measured counterclockwise from the *x*-axis. Although the data were collected at 10 Hz (except for Run 05 in the Calibration Phase at 25 Hz), only every tenth point or every 1 sec (model) or 8.7 sec (prototype) was plotted on these polar plots to make them less cluttered.

*Calibration phase*

In the Calibration Phase, there were only two current meters at locations described in Table 2. Henceforth, these two locations will be referred to as the 0-ft and 450-ft locations, corresponding to the distance along the channel centerline from the jetty base at the shoreline. Thus, the 0-ft meter is adjacent to the shoreline and the 450-ft meter is on the projection from the 450-ft-long jetty. Current data were collected for the no-jetty configuration for both wave directions. These measurements constitute a Base Case for comparisons with the Optimization Phase data. Additional current data were collected for the S25W wave direction for jetty lengths of 225 and 450 ft. These data are contained in Appendix G.

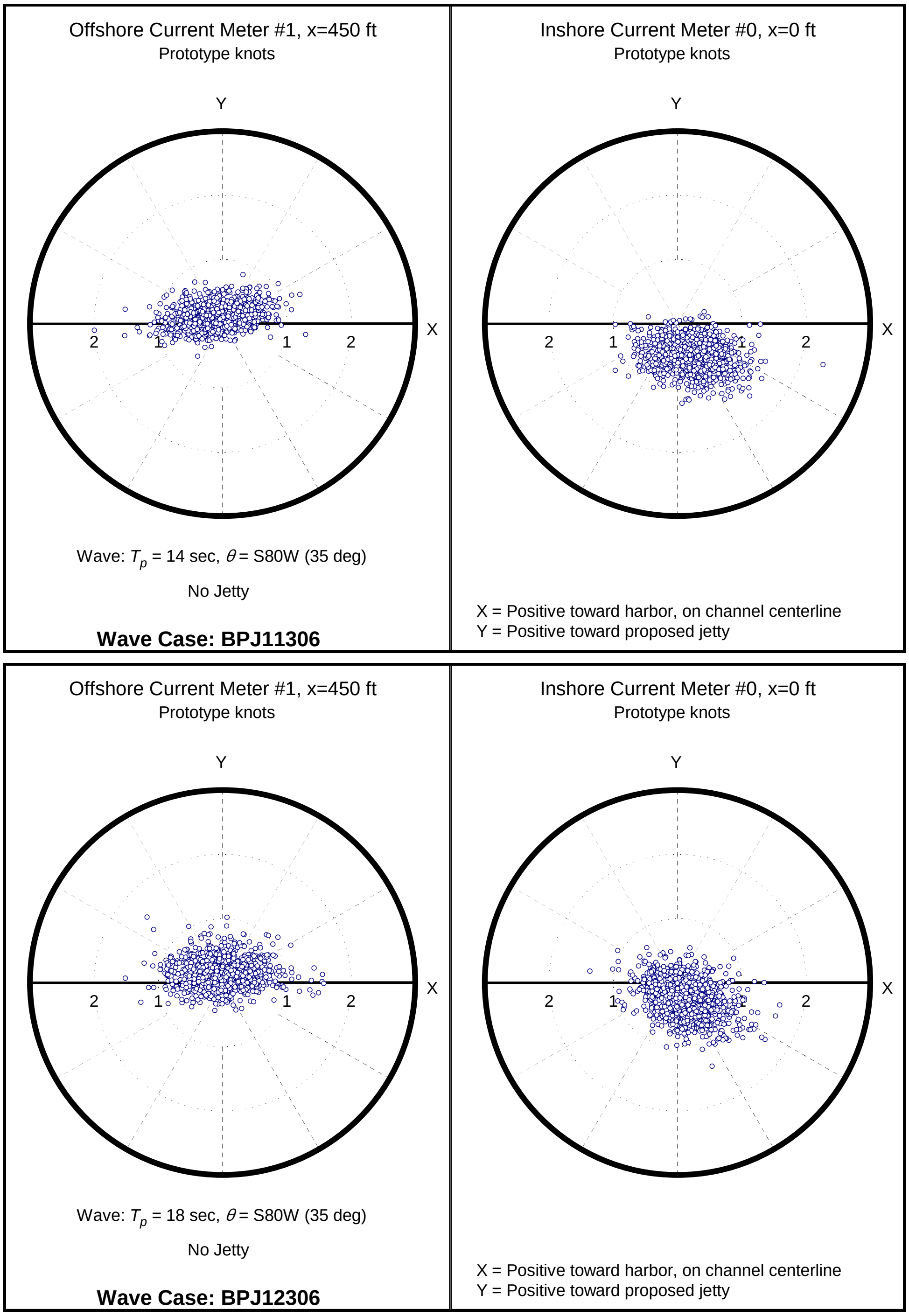
Figure 21 shows polar plots for the no-jetty Base Case for the S80W (i.e., 35 deg west, Run 06) wave direction. The figure consists of four rows of two panels for each of the four wave periods (i.e., $T_p$ = 6, 10, 14, and 18 sec) and two current meters (i.e., $x$ = 0 and 450 ft). The top row on each page is for the two current meters at $T_p$ = 6 or 14 sec. The bottom row on each page is for the two current meters at $T_p$ = 10 or 18 sec. Each symbol represents the end of a current vector, pointing from the origin toward the direction of the current. Current speed increases radially from the center with concentric circles of 1-knot magnitude. Current direction varies around a 360-deg compass with the x-axis pointing toward the harbor at N45E and $y$-axis toward the proposed jetty at N45W. For the current meters in the Calibration Phase, the positive $x$-axis direction was positioned opposite to this convention (i.e., positive toward offshore), but was reversed in the analysis to give the proper orientation.

In general, the flow comes from the top left corner of each panel for the S80W wave direction (i.e., from 35 deg west of the channel centerline). Maximum speed magnitudes are of the order of 2 kts. The flow oscillates “to and fro” along the mean wave direction. The current tends to line up with the channel because of wave refraction, diffraction, and reflection as the wave crosses the channel. For the inshore gage at $x$ = 0 ft, the current flow remained parallel to the wave direction. Flow for the offshore meter at $x$ = 450 ft, however, had a natural tendency to turn parallel to the shoreline on the west side of the channel.




(a) Top row: $T_p$ = 6 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 10 sec and $x$ = 0 and 450 ft current meter locations.

Figure 21. Current meter vector polar plots for no-jetty configuration, S80W wave direction, Calibration Phase (Continued).




(b) Top row: $T_p$ = 14 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 18 sec and $x$ = 0 and 450 ft current meter locations.

Figure 21. (concluded).

Figure 22 shows the polar plots for the no-jetty Base Case for the S25W wave direction. The format is identical to Figure 21. The mean wave direction comes from the bottom left of the panels (i.e., from 20 deg south of the channel centerline). The flow at the offshore meter turns nearly parallel with the channel, especially as wave period increases. At the inshore meter, the flow has turned substantially toward the y-axis pointing in the N45W direction. Current speed magnitudes are less than 1 knot for the offshore meter, but they increase to over 2 kts at the inshore meter. More details on the magnitudes are provided later in this section.

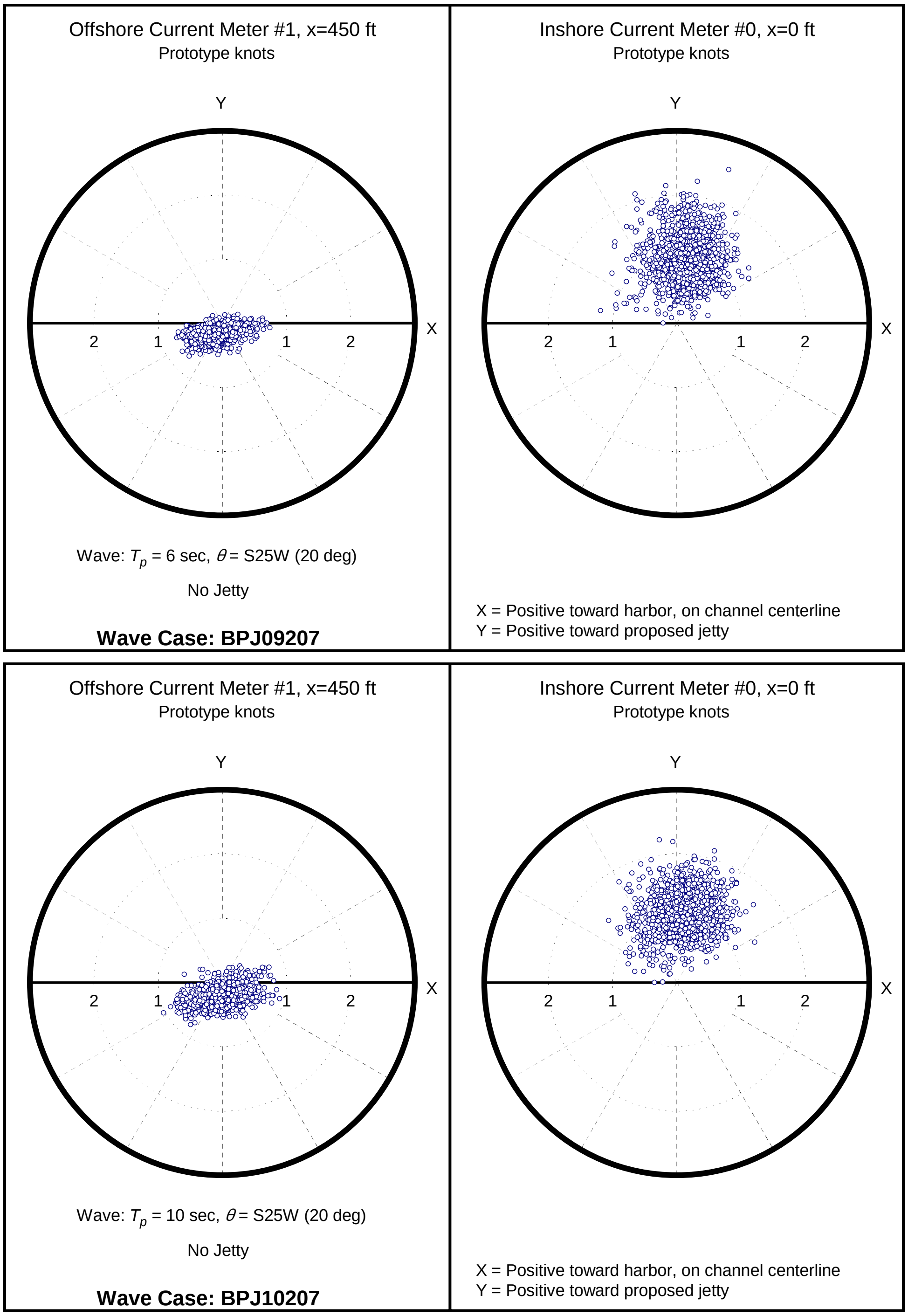
*Optimization phase*

In the Optimization Phase, there were four current meters placed at locations along the channel centerline corresponding to distances of $x$ = 300, 350, 400, and 450 ft from the shoreline. Again, the $x$=450 ft meter is on the normal projection of a 450-ft-long jetty with the channel centerline. The $x$=450 ft meter location corresponds with the offshore location (also at $x$=450 ft) in the Calibration Phase. Jetty lengths of no-jetty, 375, 400, 425, and 450 ft were tested in this phase. The no-jetty case was repeated as another Base Case with more current meters that corresponded to the cases with jetties in this phase. Only the one wave direction of S25W was tested during this phase. Thus, the incident wave direction and wave-induced longshore current are from the bottom left of each panel.

Figure 23 shows the current vector polar plots for the no-jetty Base Case (Run 35 series) for the two wave periods (i.e., $T_p$ = 6 and 18 sec). The organization of this figure is similar to the previous two figures. The main difference is that there are four meters shown on each page for only one wave period. The organization of the panels is right to left with the $x$=300 ft meter location at the top right and the $x$=350 ft meter location at the top left of each page. Likewise, the $x$=400 and 450 ft meter locations are on the bottom row of panels.

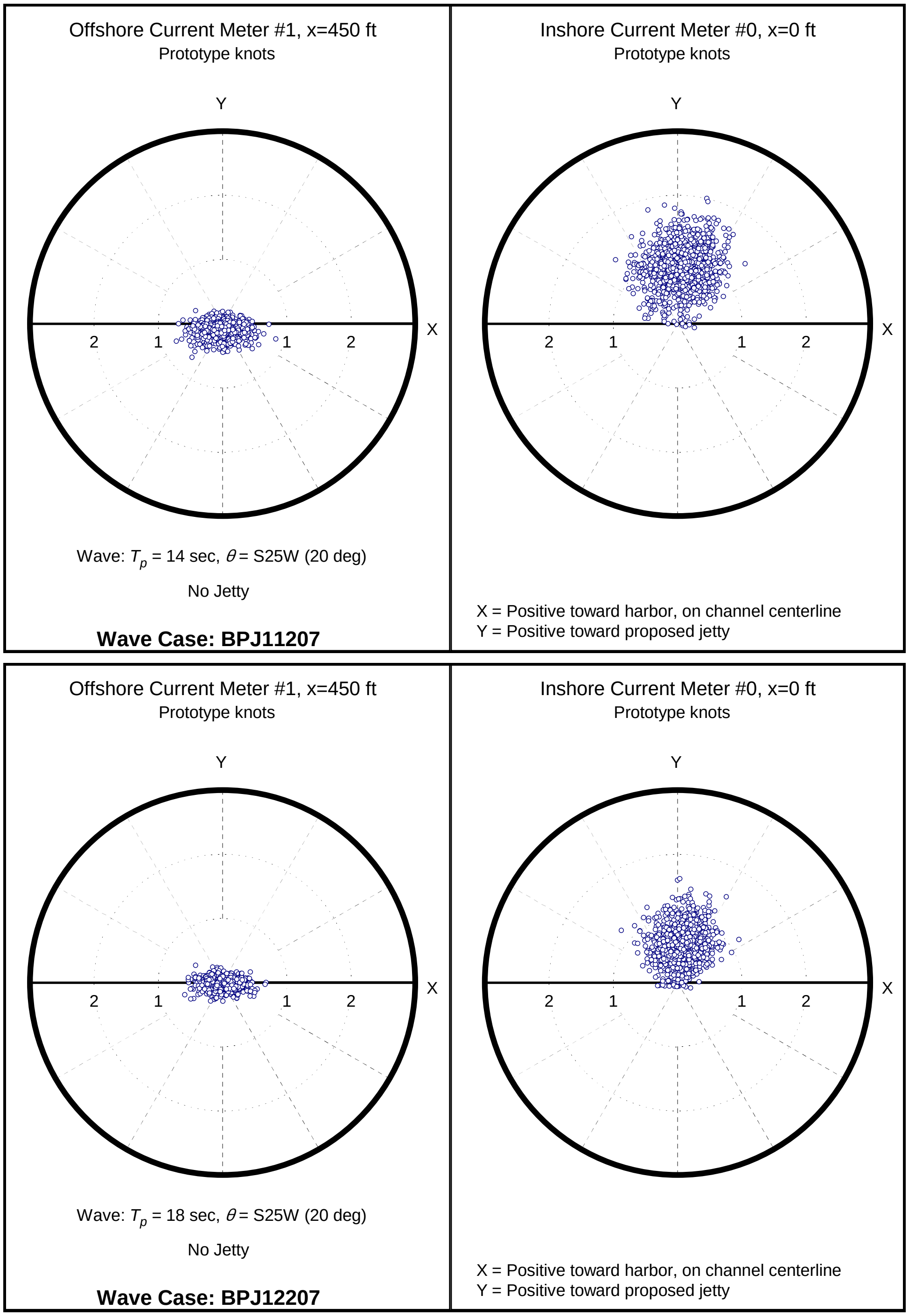
In general, the current patterns are tighter for the smaller wave period, but they spread out as wave period increases for all meter locations. The flow turns more westerly and normal to the channel centerline as the wave period increases. Since there is no-jetty, current flow tends to go straight across the channel and parallel to the shoreline on the west side of the channel.

Figures 24 to 25 are polar plots for the 375- and 450-ft-long jetties, respectively. These are the shortest and longest jetty lengths tested in the Optimization Phase. The format for these figures is identical to Figure 23. The flow patterns for the 375-ft-long jetty are similar to the case with no-jetty, except that the flow tends to turn more to the southwest as it flows out along the jetty toe. There is not much difference due to the longer 450-ft-long jetty, except that the flow turns more because of the longer length. The trends for the $T_p$ = 10 and 14 sec cases are similar and shown in Appendix G, along with the 400- and 425-ft-long jetty cases.



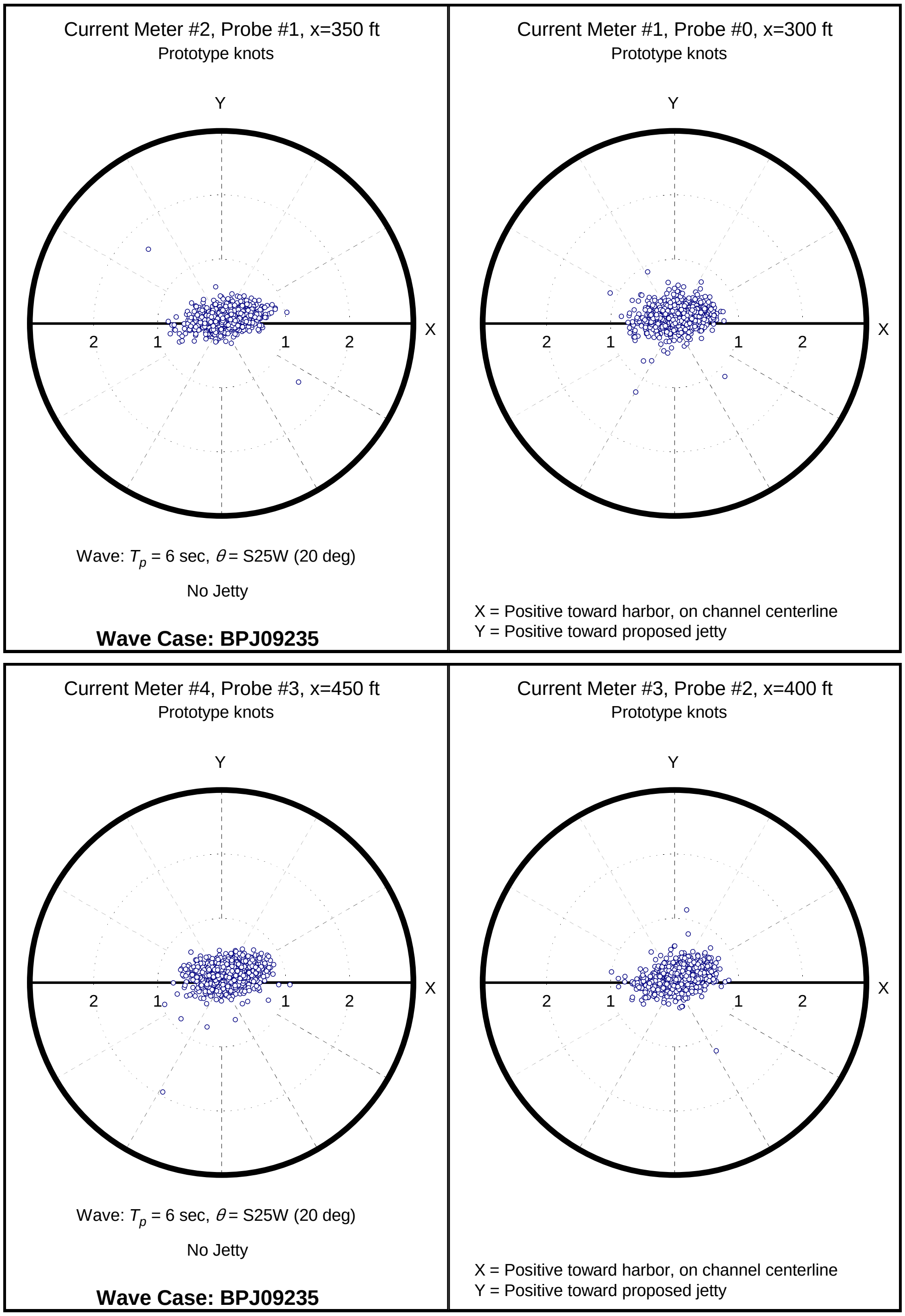

(a) Top row: $T_p$ = 6 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 10 sec and $x$ = 0 and 450 ft current meter locations.

Figure 22. Current meter vector polar plots for no-jetty configuration, S25W wave direction, Calibration Phase (Continued).



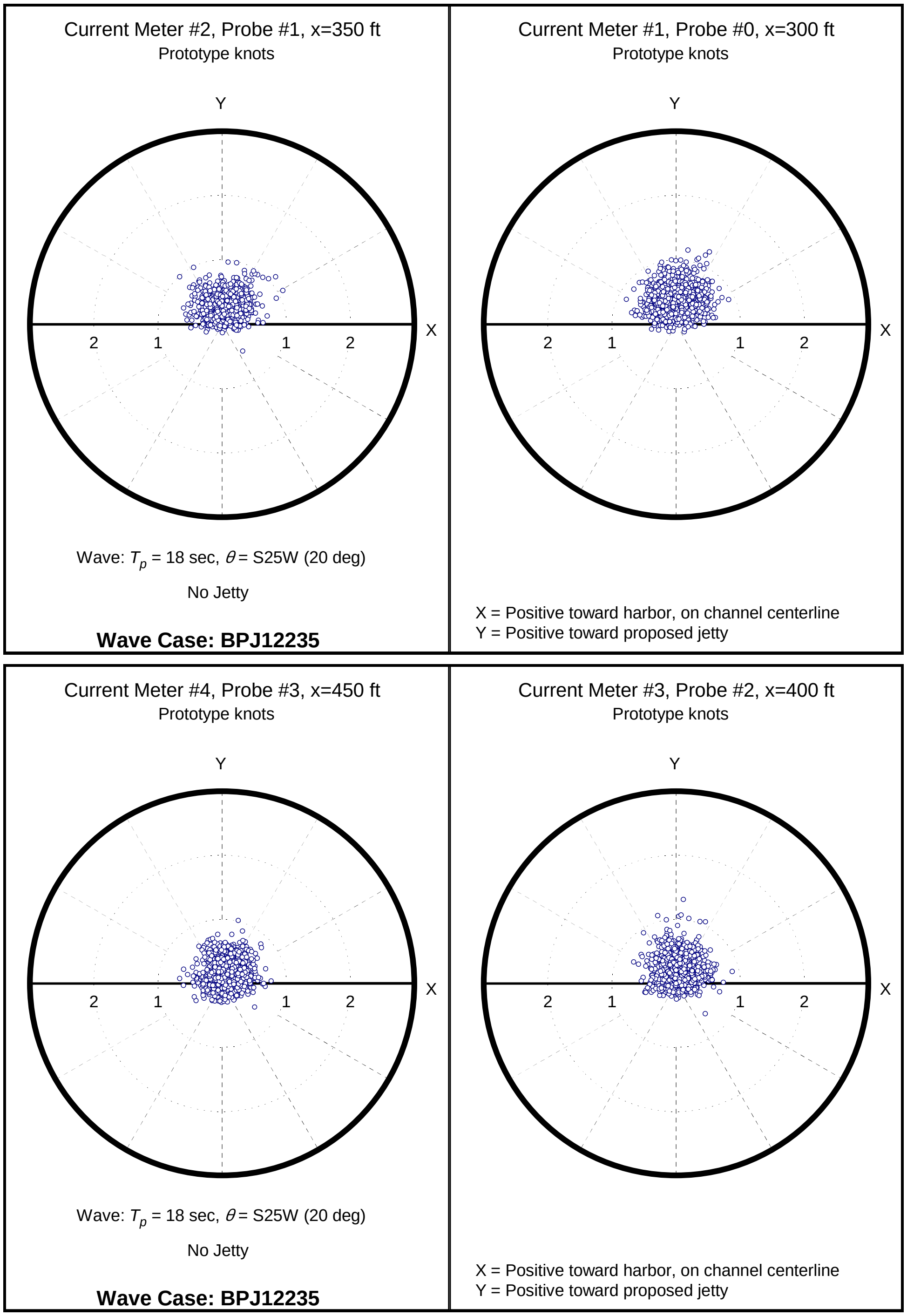

(b) Top row: $T_p$ = 14 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 18 sec and $x$ = 0 and 450 ft current meter locations.

Figure 22. (Concluded).



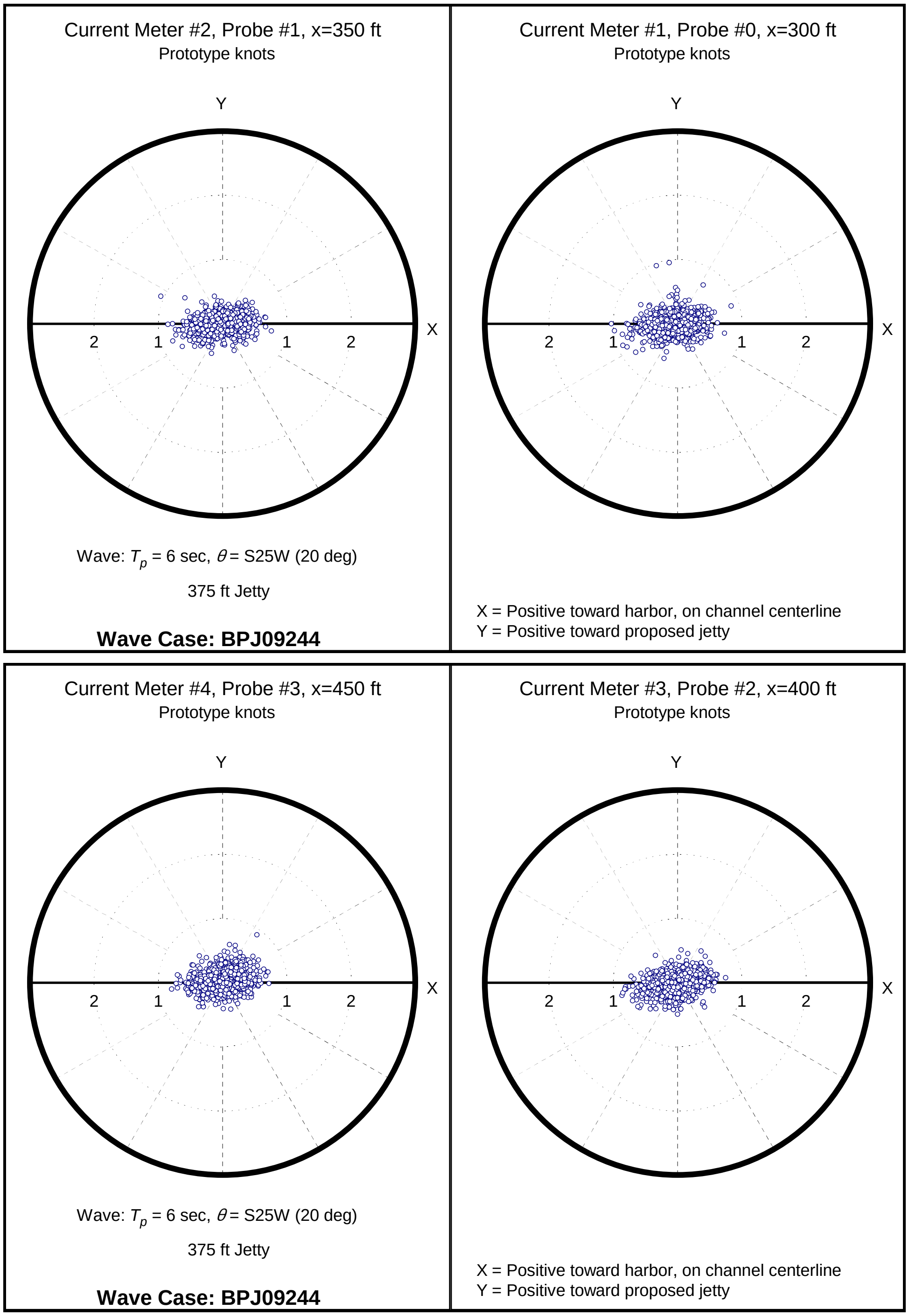

(a) $T_p$ = 6 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure 23. Current vector polar plots for no-jetty configuration, S25W wave direction, Optimization Phase (Continued).



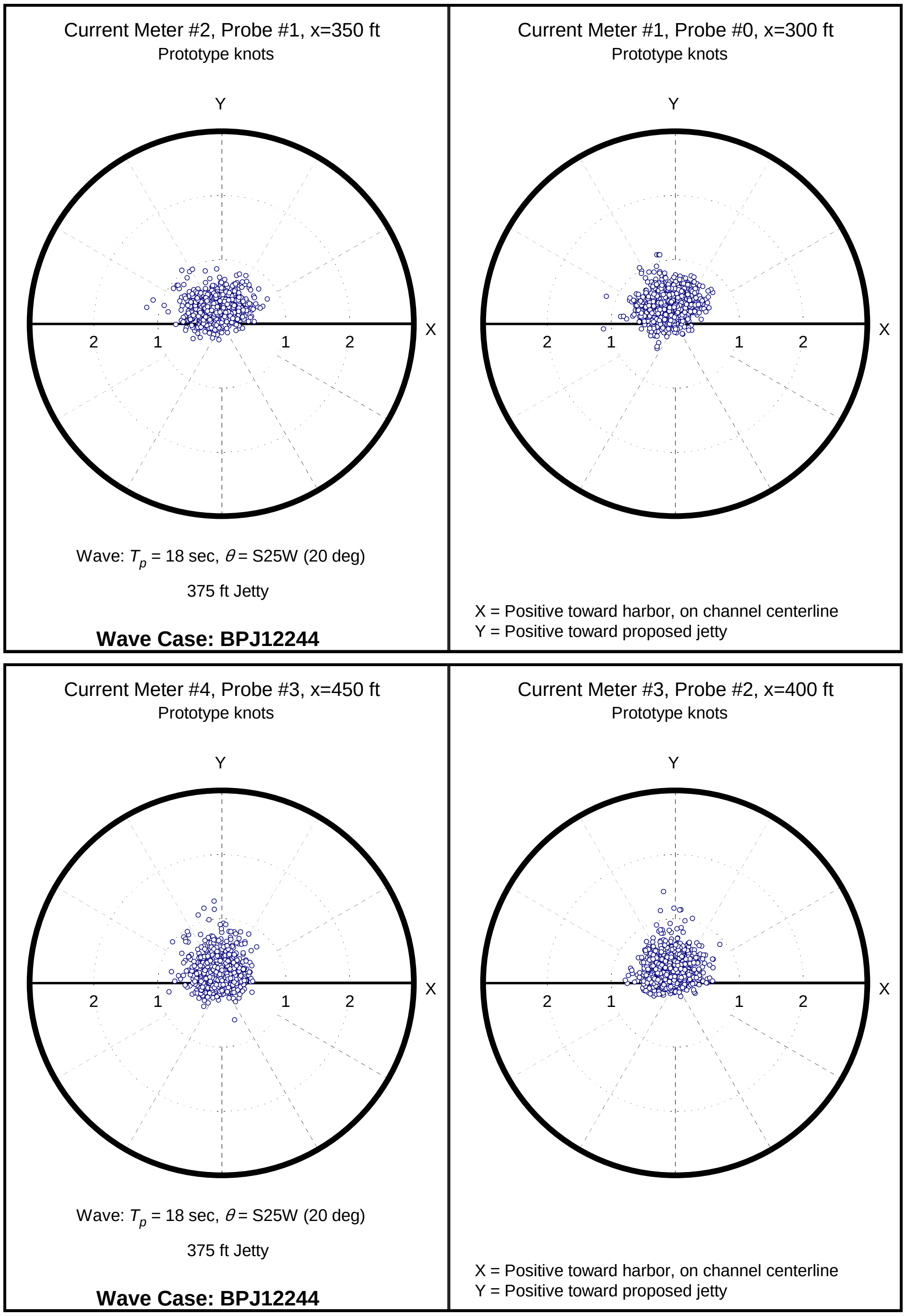

(b) $T_p$ = 18 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure 23. (Concluded).



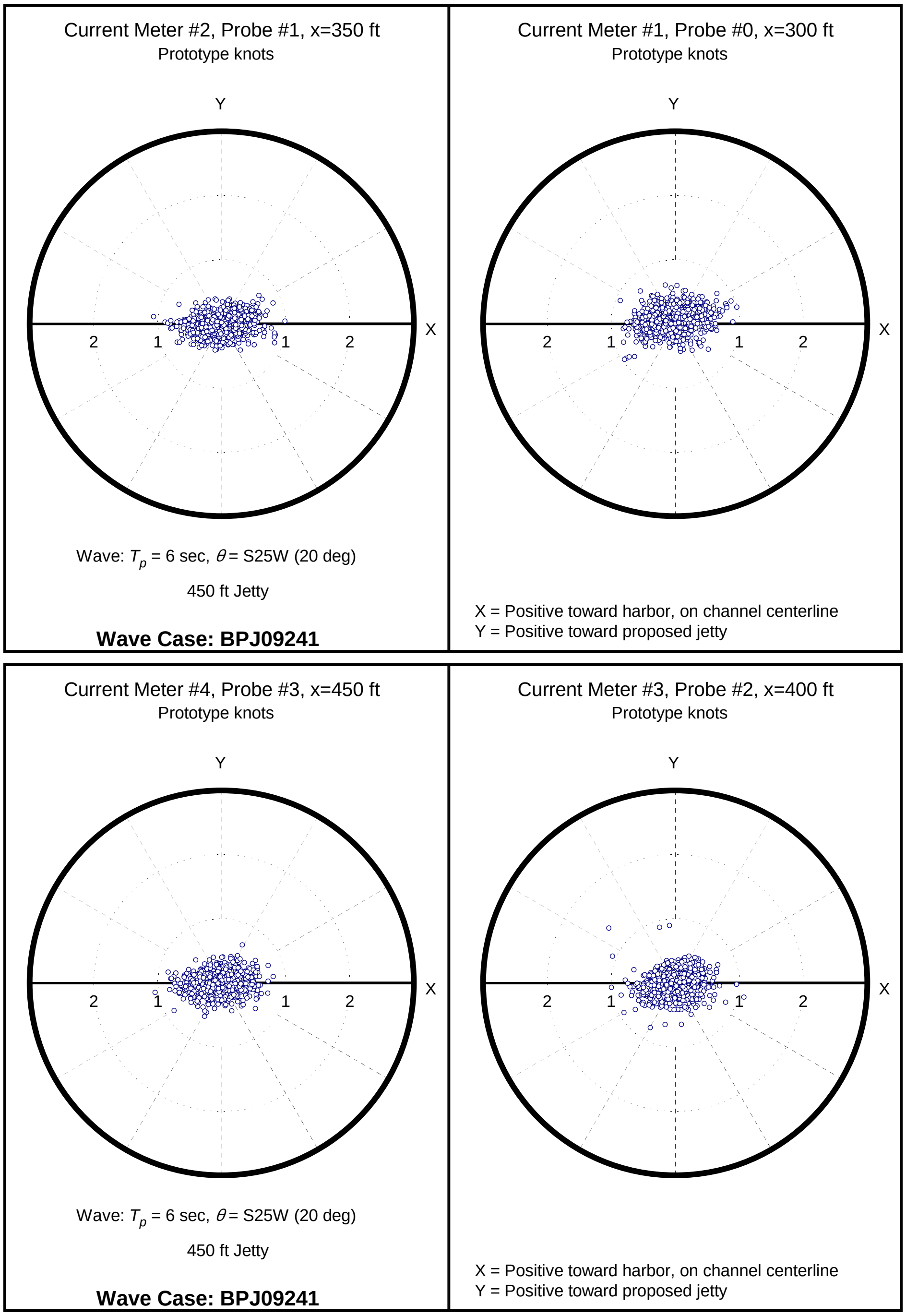

(a) $T_p$ = 6 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure 24. Current vector polar plots for 375-ft-long jetty configuration, S25W wave direction, Optimization Phase (Continued).



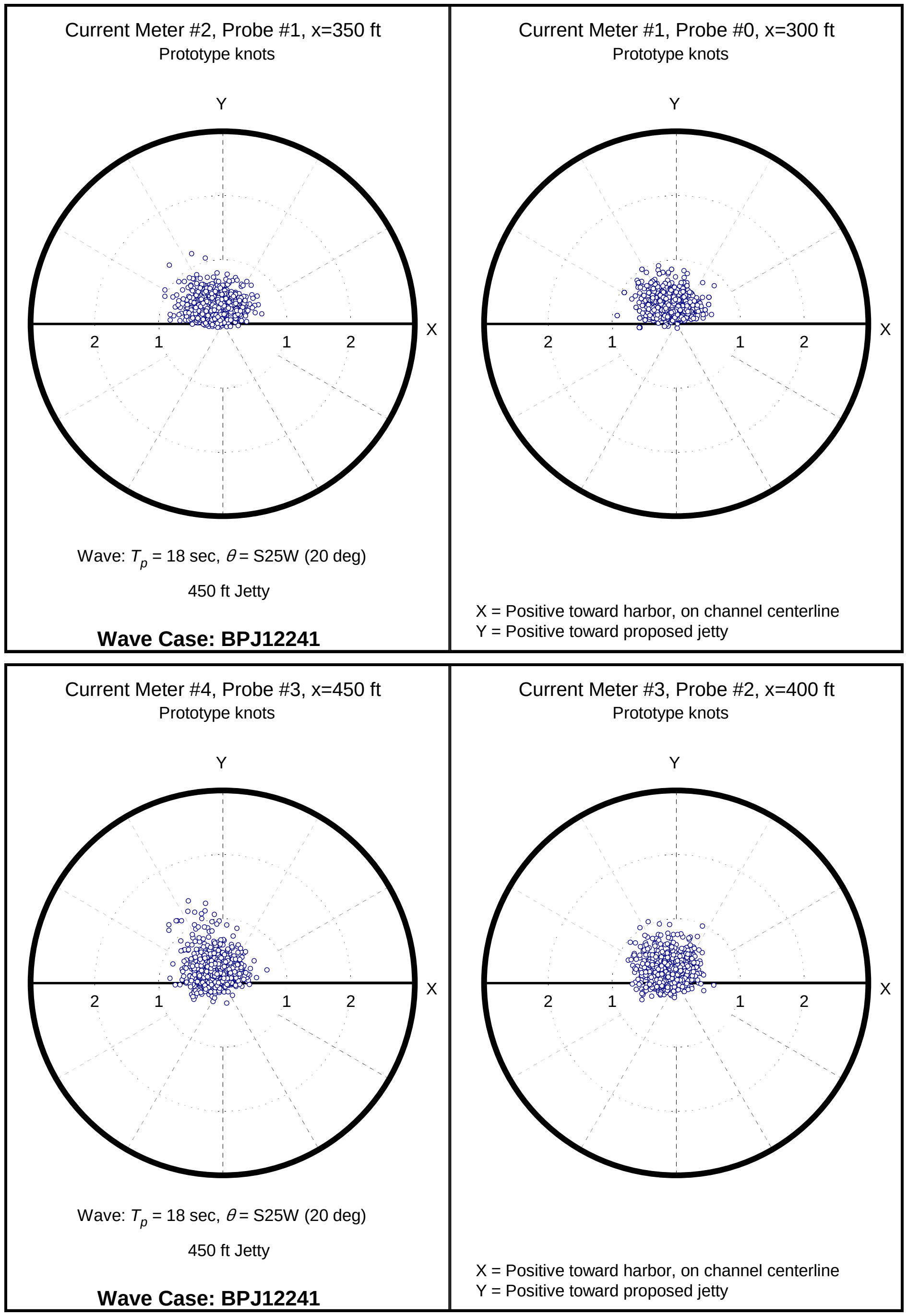

(d) $T_p$ = 18 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure 24. (Concluded).




(a) $T_p$ = 6 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure 25. Current vector polar plots for 450-ft-long jetty configuration, S25W wave direction, Optimization Phase (Continued).




(d) $T_p$ = 18 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure 25. (Concluded).

### Current magnitudes

The current magnitudes $V(t)$ in the current vector polar plots were plotted as a function of time, based on the $u$- and $v$-components from each current meter. In this section, the $V_{m0}$ current magnitudes were calculated in the frequency domain from the zero moment $m_0$, much like $H_{m0}$ wave heights.

Thus, these $V_{m0}$ magnitudes will be approximately 1.6 times larger than the mean values used in the polar plots, assuming the currents follow a Normal or Gaussian distribution.

*Calibration phase*

Figure 26 shows the variation of the $V_{m0}$ current magnitudes for the onshore and offshore current meter locations (i.e., $x$ = 0 and 450 ft) for the S80W wave direction. Since only the no-jetty configuration was tested, all four wave cases are included on this single plot. The magnitudes are averaged for the two runs (i.e., Run 05 and 06). Note that since there were only two current meters, the points are not connected because the trends between these two points are probably not linear. The overall trend is slightly larger currents near the shore, decreasing offshore. This is probably due to the focusing effect of the shoreline on the current flow. The current is largest at the shore, in agreement with the large current shears noticed near the shoreline. The variation in current magnitude with wave period follows the trend of the wave heights.

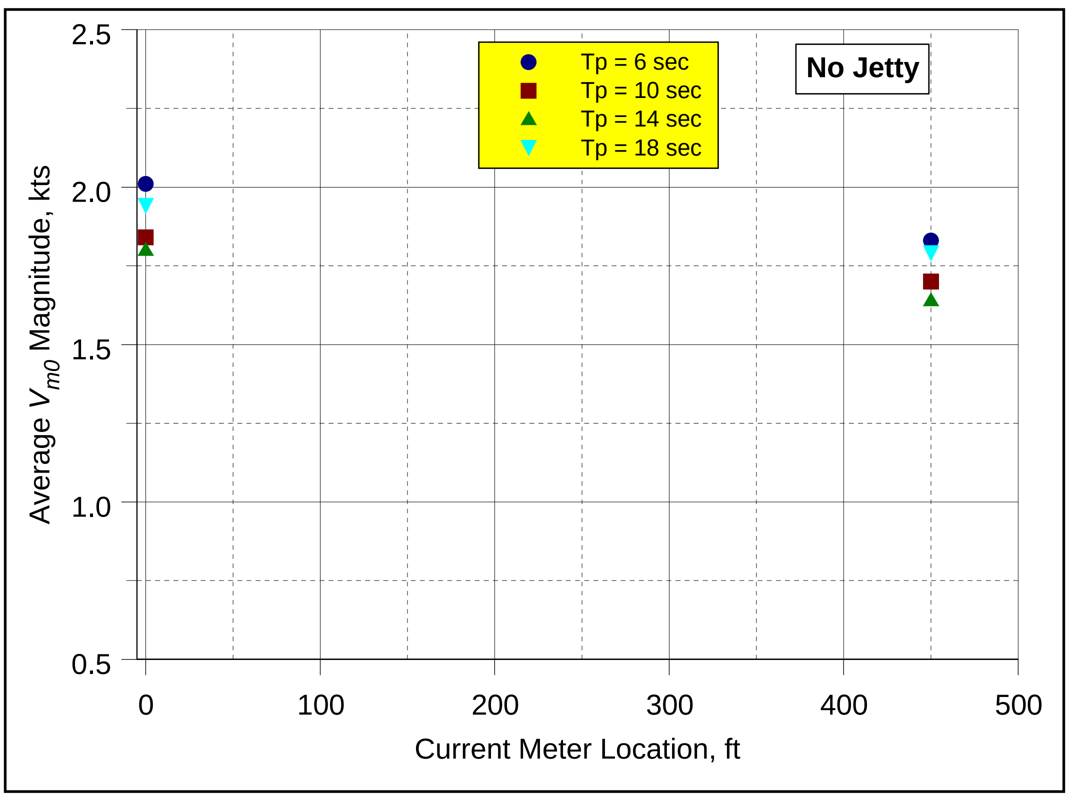



Figure 26. Average current $V_{m0}$ magnitude for no-jetty configuration, four wave cases, S80W wave direction, Calibration Phase.

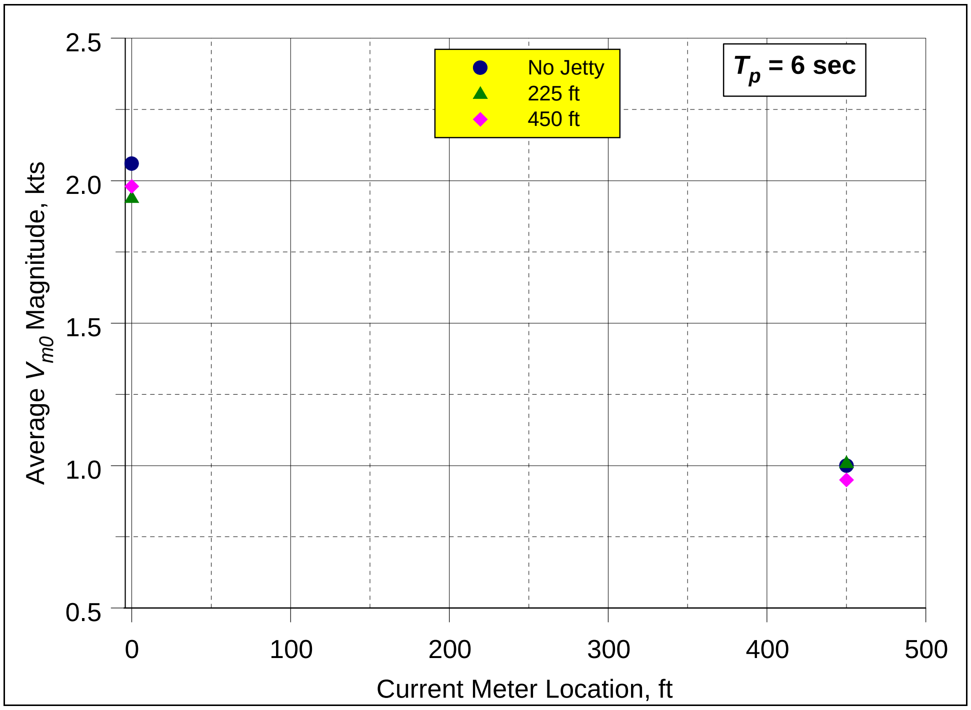
For the S25W wave direction, there were three jetty configurations tested for each of the four wave cases. Figure 27 shows the measured current magnitudes for these cases. The trend is the same as the previous figure, but with a larger decrease in current magnitude with distance offshore (i.e., larger slope). The magnitudes were normalized by the corresponding magnitude for the no-jetty configuration to better illustrate the effect of the jetty on the current. These normalized values are shown in Figure 28. The maximum variation from the no-jetty condition is 12.5 percent for the offshore meter location, $T_p$ = 18 sec, and 225-ft-long jetty. The effect of the jetty does not seem to be significant as there is very little change in the current magnitude with increase in jetty length. Tabular listings of the magnitudes and normalized values are contained in Appendix H.

*Optimization phase*

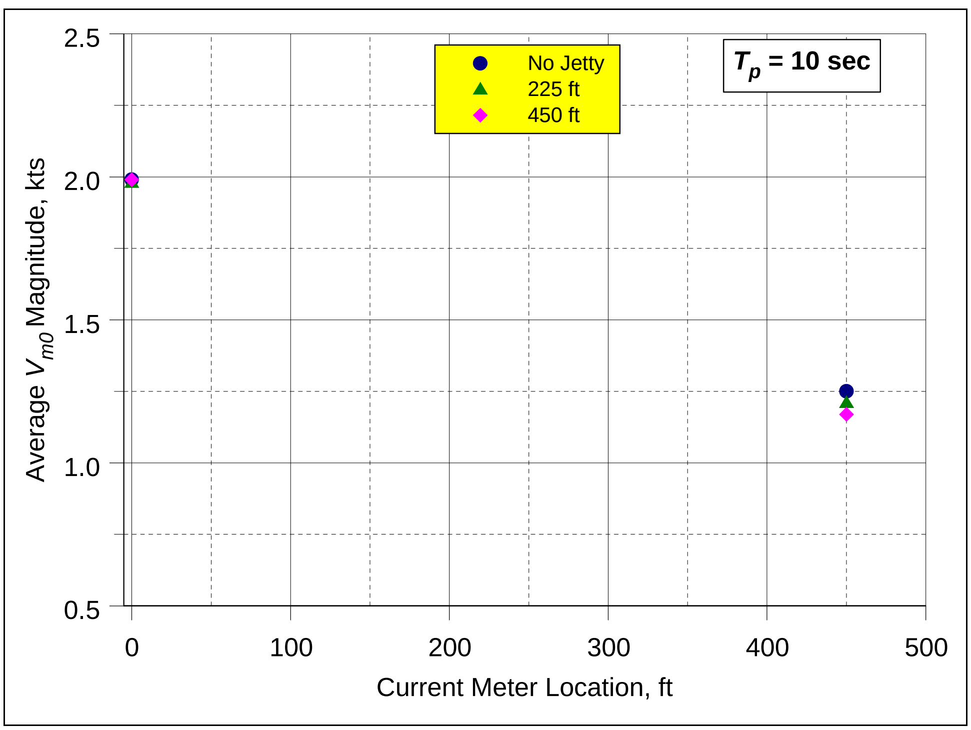
Figure 29 shows the average $V_{m0}$ current magnitudes for the four current meters located at $x$ = 300, 350, 400, and 450 ft in the Optimization Phase. This figure has the same format as Figure 27 for the Calibration Phase, except that the x-axis scale goes from 250 to 500 ft to provide better detail. Prototype current is plotted versus current meter location for each of the four proposed jetty lengths. The Base Case with no-jetty is also plotted for reference. Each curve was again normalized by the no-jetty case. These normalized values are shown for the four wave cases in Figure 30, which is similar to Figure 28 for the Calibration Phase. Tabular listings of these magnitudes and normalized magnitudes are contained in Appendix H.

Ideally, the best case would be the one with little of no change relative to this Base Case with no-jetty. The 375-ft-long jetty had both the largest decrease and increase in magnitude relative to the no-jetty configuration at the $x$ = 300 ft current meter location. It had a 29 percent decrease at $T_p$ = 6 sec and a 10 percent increase at $T_p$ = 10 sec. In general, there was very little variation in current magnitude and direction as a function of wave period, jetty length, and location. Some jetty lengths were slightly better than others for different wave periods and locations in the channel. However, these differences are so small that they are not statistically significant.

Dean and Dalrymple (2002) use an even-odd analysis as a method of determining the effects of natural or man-made features on coastlines. It has been predominantly used in sediment transport applications to study

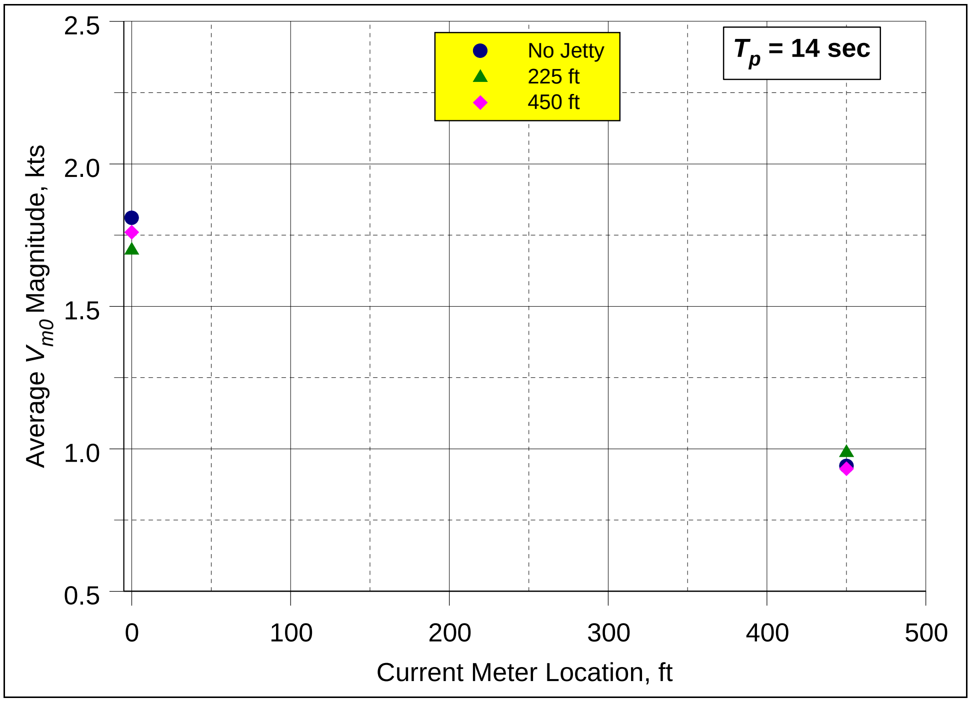



(a) $T_p$ = 6 sec, $x$ = 0 and 450 ft current meter locations.

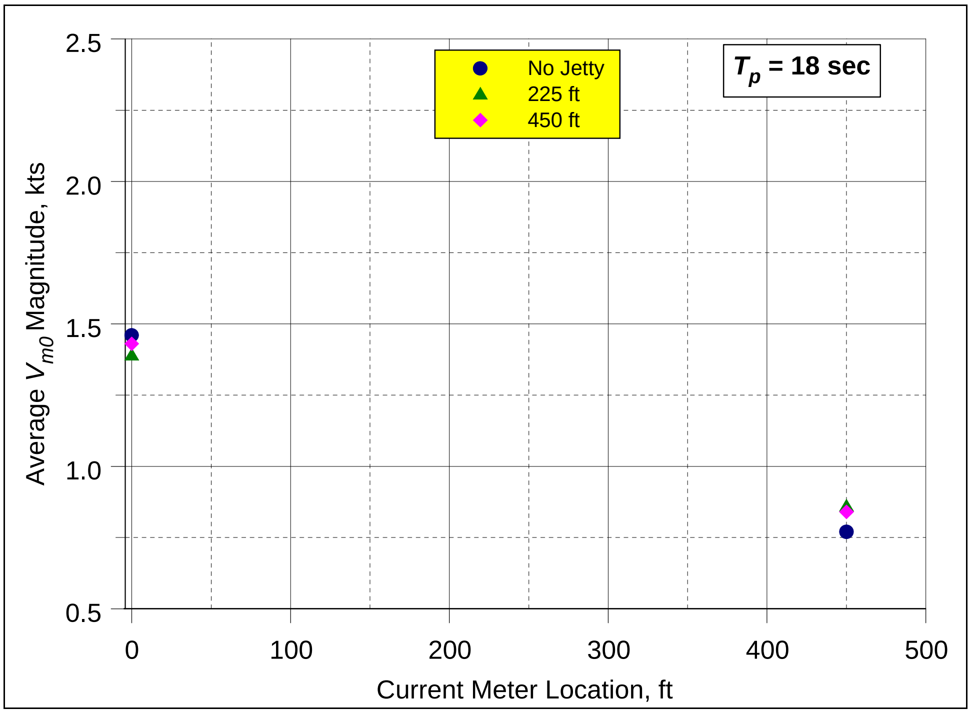



(b) $T_p$ = 10 sec, $x$ = 0 and 450 ft current meter locations.

Figure 27. Average current $V_{m0}$ magnitude for three jetty configurations, four wave cases, S25W wave direction, Calibration Phase (Continued).

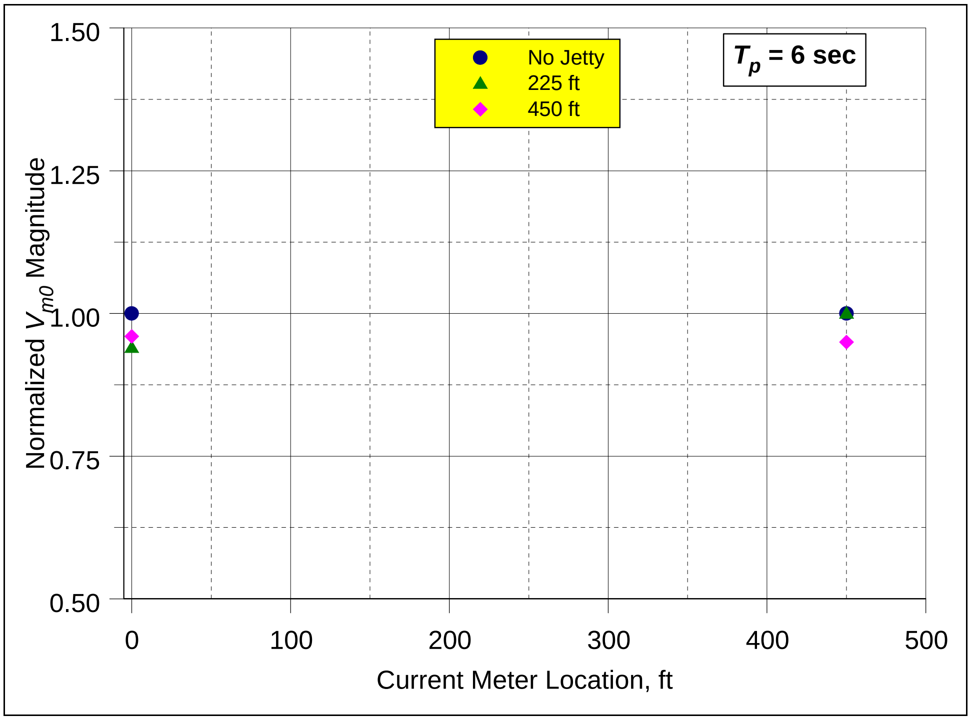



(c) $T_p$ = 14 sec, $x$ = 0 and 450 ft current meter locations.

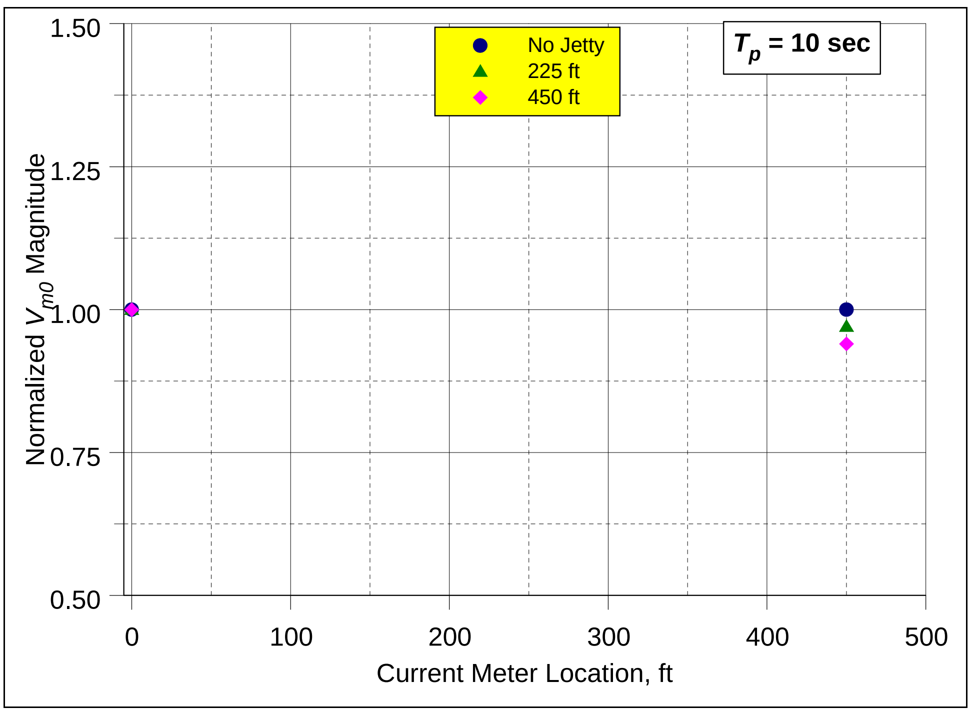



(d) $T_p$ = 18 sec, $x$ = 0 and 450 ft current meter locations.

Figure 27. (Concluded).

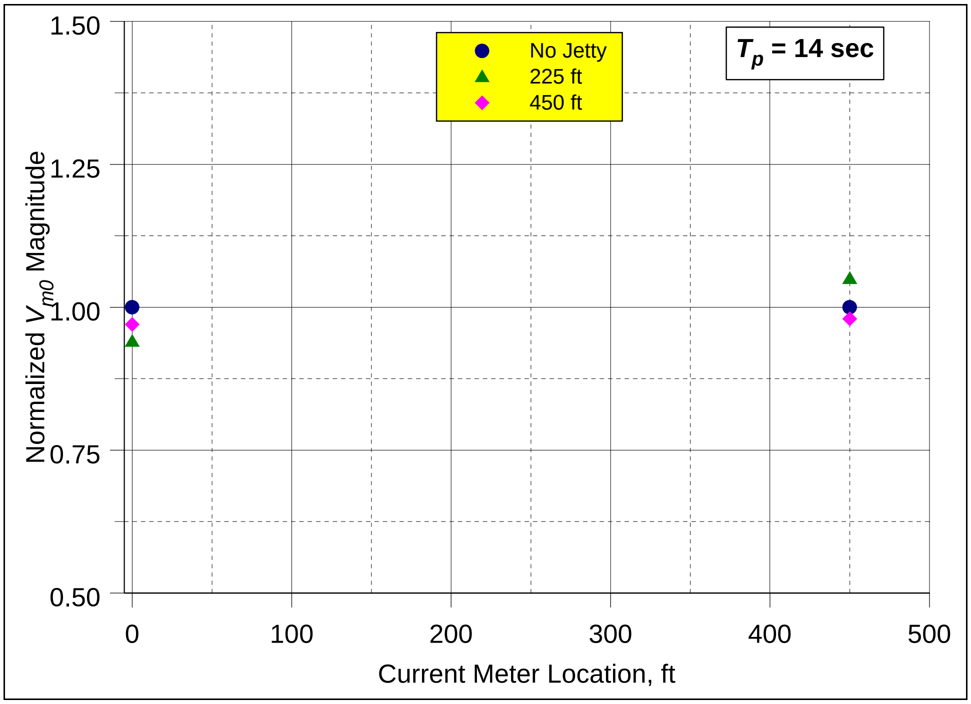



(a) $T_p$ = 6 sec, $x$ = 0 and 450 ft current meter locations.

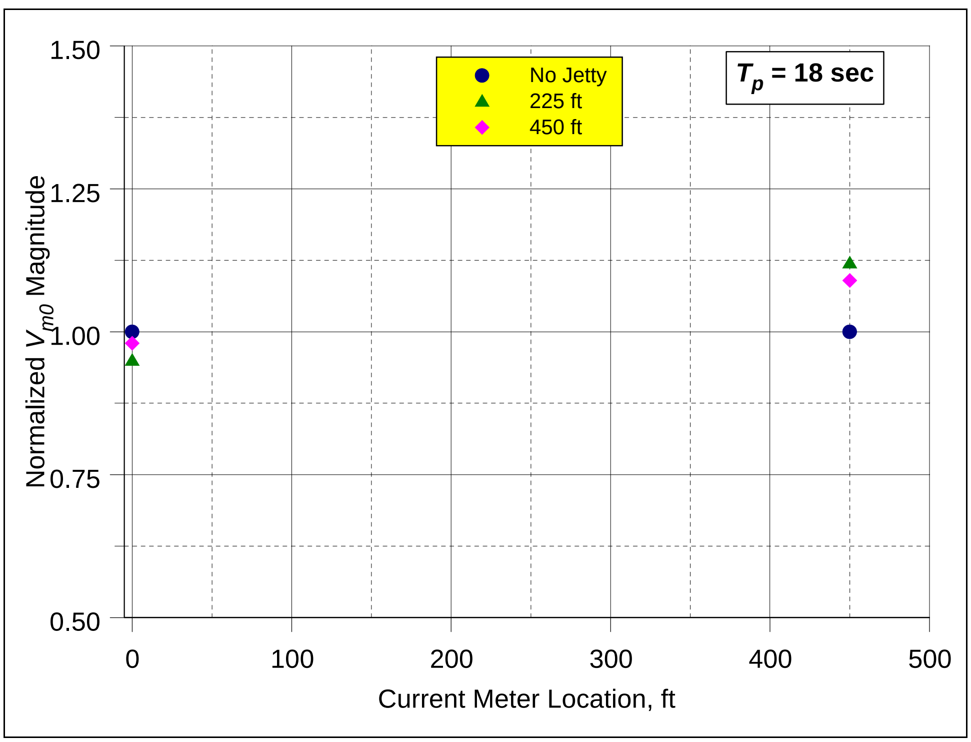



(b) $T_p$ = 10 sec, $x$ = 0 and 450 ft current meter locations.

Figure 28. Normalized current $V_{m0}$ magnitude for three jetty configurations, four wave cases, S25W wave direction, Calibration Phase (Continued).

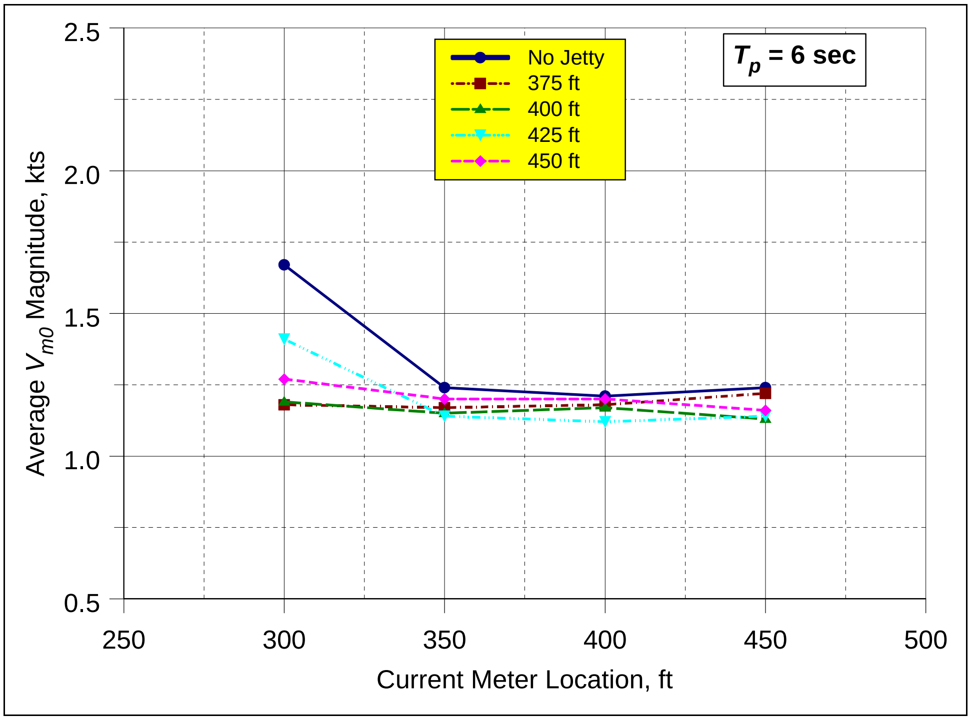



(c) $T_p$ = 14 sec, $x$ = 0 and 450 ft current meter locations.

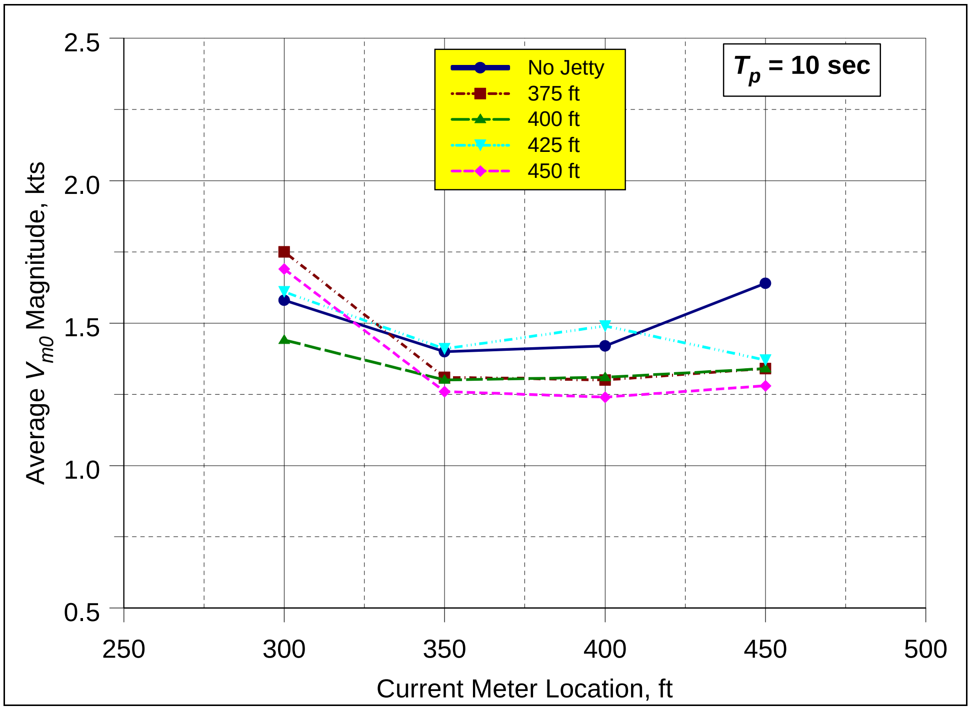



(d) $T_p$ = 18 sec, $x$ = 0 and 450 ft current meter locations.

Figure 28. (Concluded).

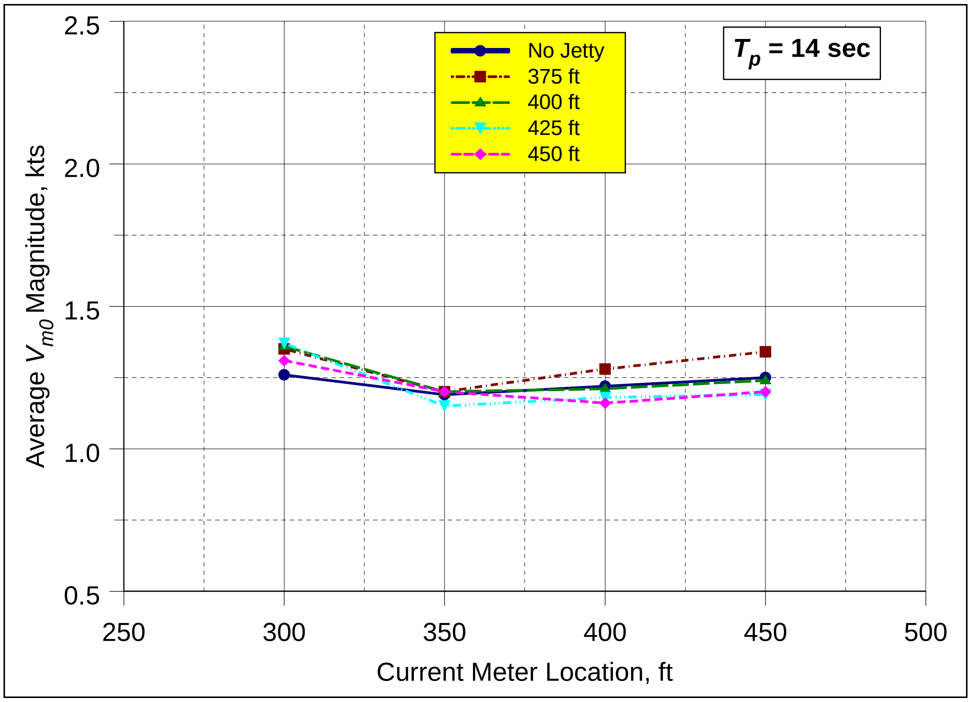



(a) $T_p$ = 6 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

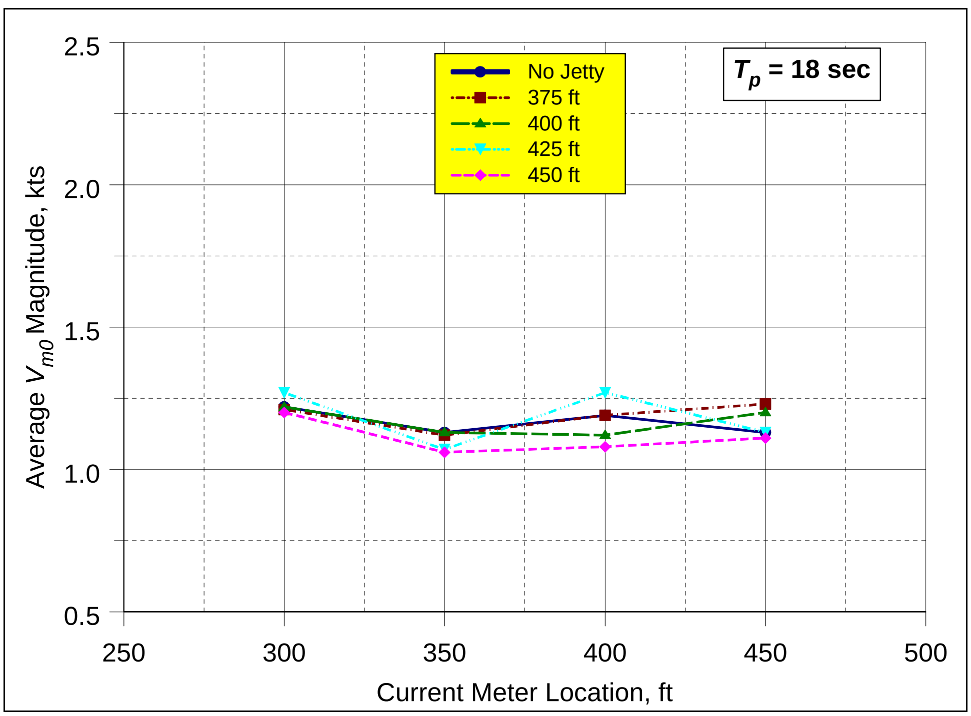



(b) $T_p$ = 10 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

Figure 29. Average current $V_{m0}$ magnitude for five jetty configurations, four wave cases, S25W wave direction, Optimization Phase (Continued).

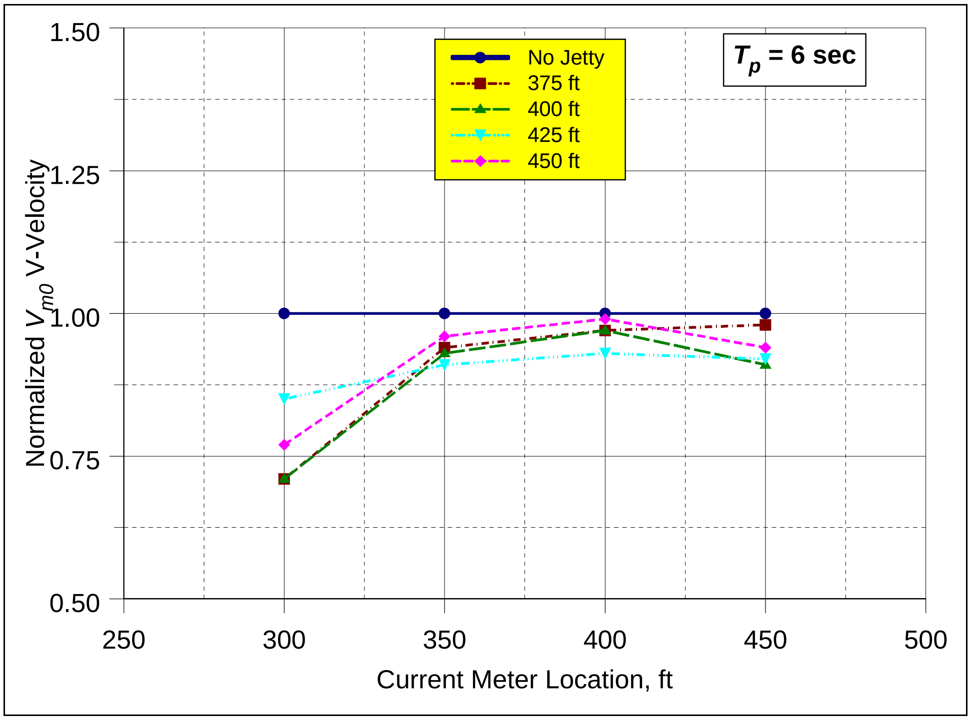



(c) $T_p$ = 14 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

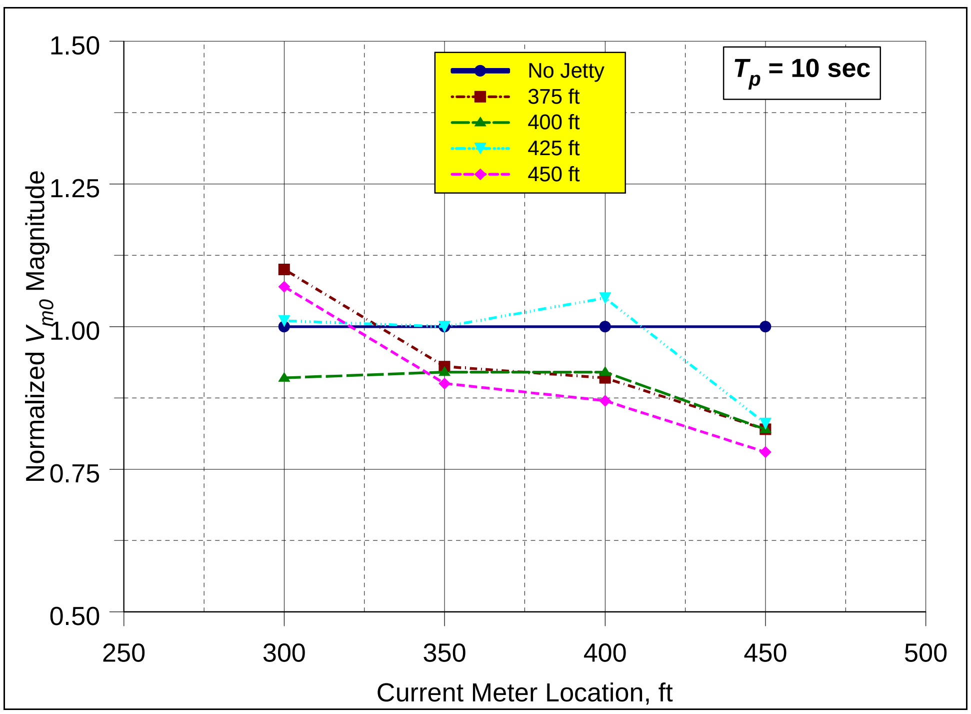



(d) $T_p$ = 18 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

Figure 29. (Concluded).

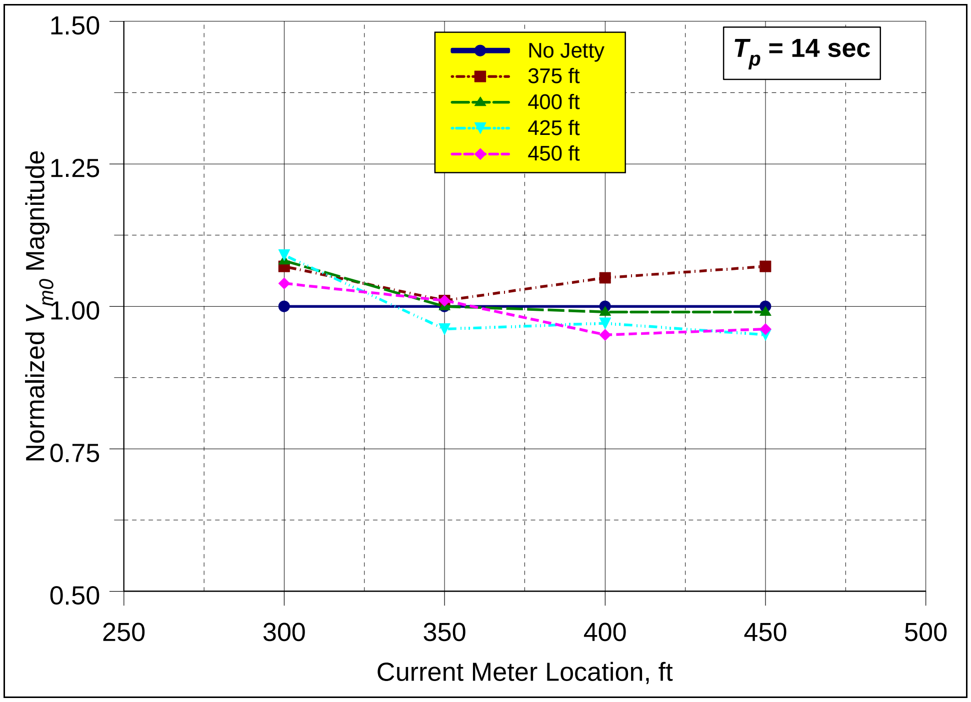



(a) $T_p$ = 6 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

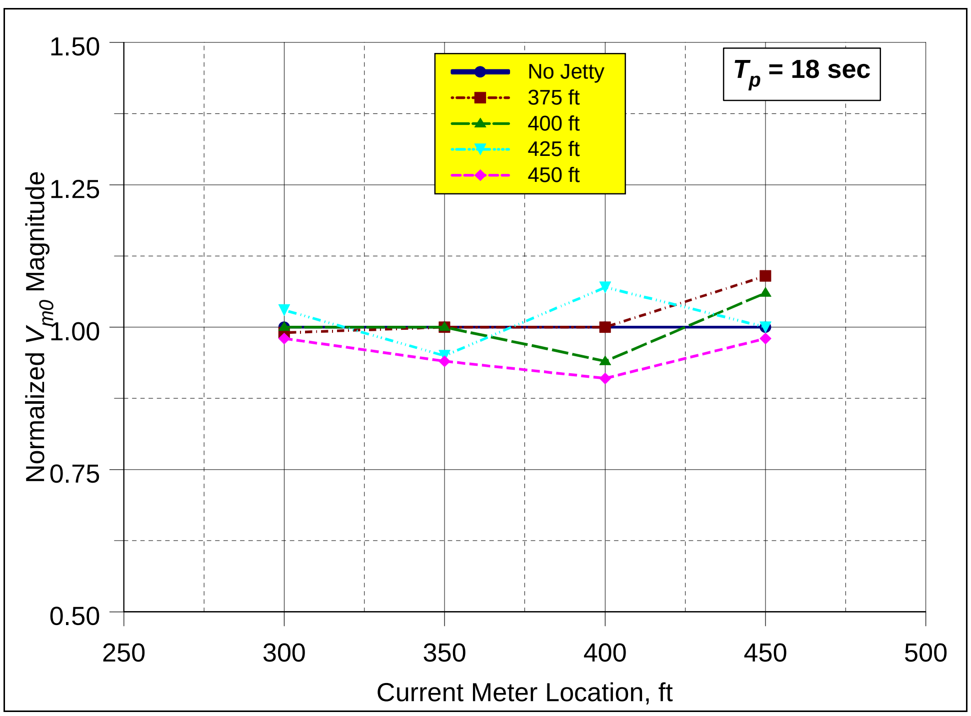



(b) $T_p$ = 10 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

Figure 30. Normalized current $V_{m0}$ magnitude for five jetty configurations, four wave cases, S25W wave direction, Optimization Phase (Continued).




(c) $T_p$ = 14 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.




(d) $T_p$ = 18 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

Figure 30. (Concluded).

the effects of groins, inlets, etc. The basic idea is to separate the changes in the data into symmetric and antisymmetric components. The symmetric or even components can be interpreted as changes that are ongoing and may not be attributable to the coastal structure. The antisymmetric or odd components represent changes that are due to the structure.

The total change in current $V_{m0}$ magnitude $\Delta V_s(x)$ can be expressed as the sum of the even and odd components as

$$\Delta V_s(x) = \Delta V_e(x) + \Delta V_o(x) \qquad (1)$$

where $\Delta V_e(x)$ is the even component and $\Delta V_o(x)$ is the odd component. The formulas for the even and odd components are given by

$$\Delta V_e(x) = \frac{\Delta V_s(x) + \Delta V_s(-x)}{2} \qquad (2)$$

$$\Delta V_o(x) = \frac{\Delta V_s(x) - \Delta V_s(-x)}{2} \qquad (3)$$

In the sediment transport applications, the coastal structure marks the origin, with negative $x$-locations on the updrift side and positive $x$-locations on the downdrift side. In this application to investigate the effect of different jetty lengths, the four current meter locations from $x$ = 300 to 450 ft form the set of positive and negative $x$-locations and corresponding magnitude measurements. The origin is selected in the middle of these four meters at $x$ = 375 ft. Thus, two meters are located to the left (i.e., negative $x$-direction or shoreward) and two meters to the right (i.e., positive $x$-direction or seaward) of the origin. The first step is to calculate the net magnitude change for the different jetty configurations relative to the Base Case with no-jetty. The even and odd functions are then calculated at each current meter location using the equations above. Finally, the even and odd functions are averaged over all wave conditions for each jetty configuration.

Figure 31 shows the even and odd components for these averages over all wave conditions. The format is similar to the previous figures. The ideal is for no change in magnitude. The even function illustrates the symmetric changes that would occur for the different jetty lengths. The odd function shows the antisymmetric changes due to the different jetty lengths. In the even analysis, the 375- and 425-ft-long jetty configurations have the least amount of change. Note that the change is negative or smaller for all jetty configurations relative to the base no-jetty case. For the odd analysis, the 375- and 400-ft-long jetty configurations are the best choices. Overall, the 375-ft-long jetty is the better choice, as it provides the least interference or change in the existing currents for all current meter locations and wave conditions. Tabular listings of the measured magnitudes and even and odd analysis results are contained in Appendix I.

### Current shears

The ships sometimes experience a current shear which can lead to dangerous yawing and drifting toward the channel sides. A good measure of this current shear is the $v$-component (i.e., $y$-axis) current velocity.

#### *Calibration phase*

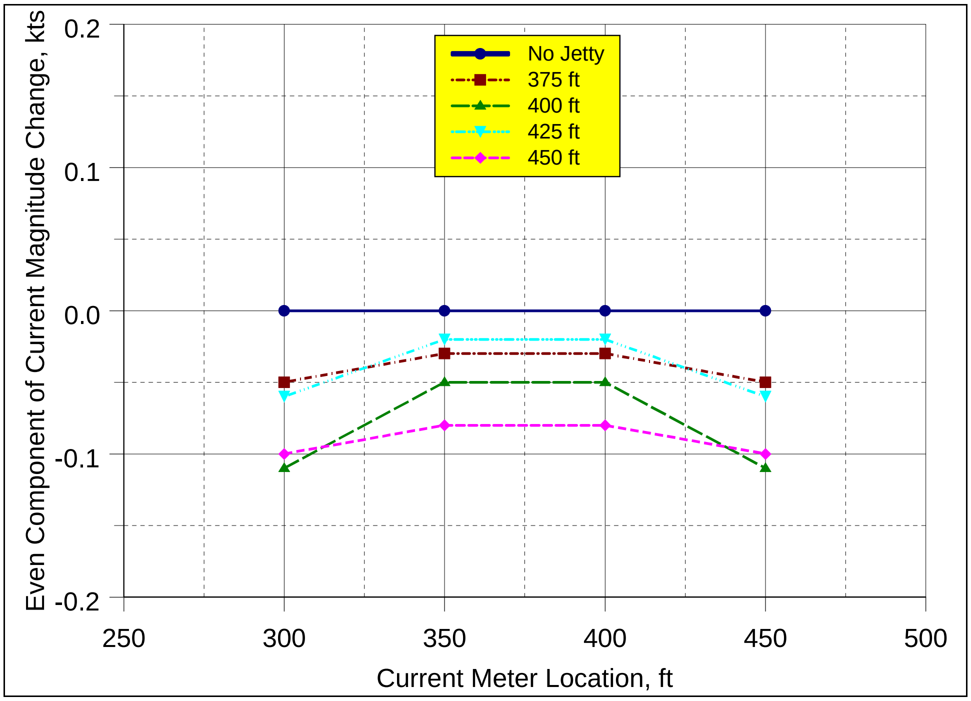
In the Calibration Phase, the $v$-velocity component has similar trends to the magnitudes shown in Figures 26 and 27, except that the values are smaller since they do not include the $x$-axis or $u$-velocity component. They are not shown here.

#### *Optimization phase*

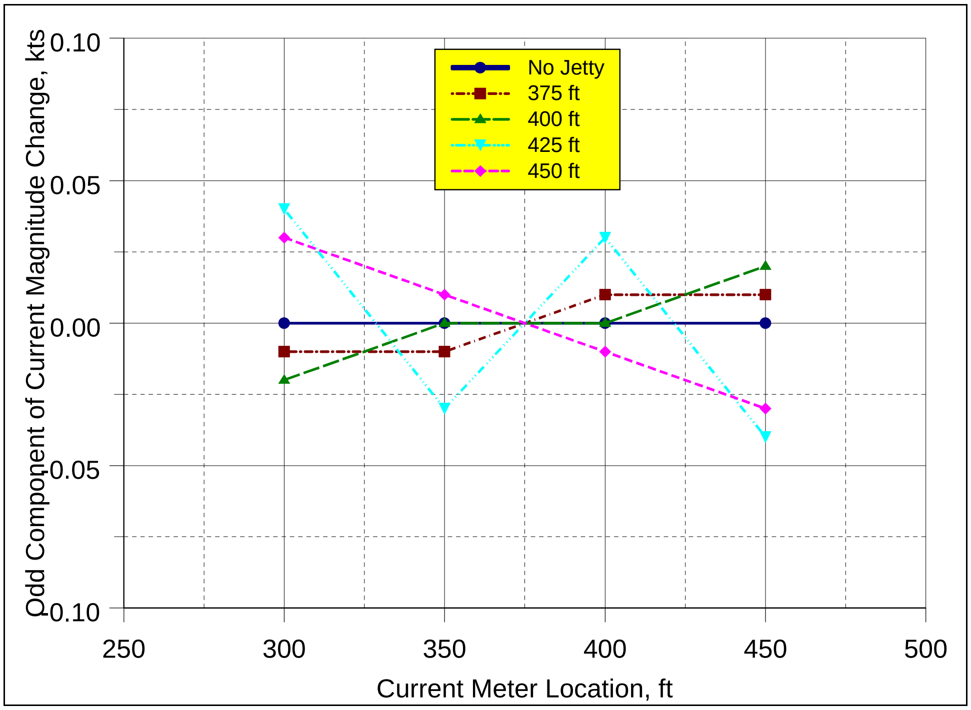
The $v$-velocity component was again normalized by the no-jetty case. These values are shown in Figure 32, which has the same format as previous figures. For the $T_p$ = 6 sec case, the 375- and 425-ft-long configurations are closest to the no-jetty Base Case. The 400- and 425-ft-long configurations look best for the $T_p$ = 10 sec case. The 375-ft-long is probably the best configuration for the $T_p$ = 14 and 18 sec case, even though the $x$ = 450 ft location is somewhat larger.

The Even-Odd Analysis is again used to make more sense of the data. The average even and odd components for all wave periods are shown in Figure 33. The even analysis indicates that both the 375- and 425-ft-long configurations may have the least $V$-velocity changes. The odd analysis components, however, clearly show that the 375-ft-long configuration is the best choice to minimize velocity shears. The slope is the same for this case versus several reversals in the 425-ft-long configuration that would pose more problems for the ships transiting this portion of the entrance channel.

An assumption was made that the smaller this component, especially relative to the Base Case, the less dangerous the shearing condition would be. However, there is not a lot of variation among jetty lengths for any of the wave periods, and the magnitude of these changes is very small.

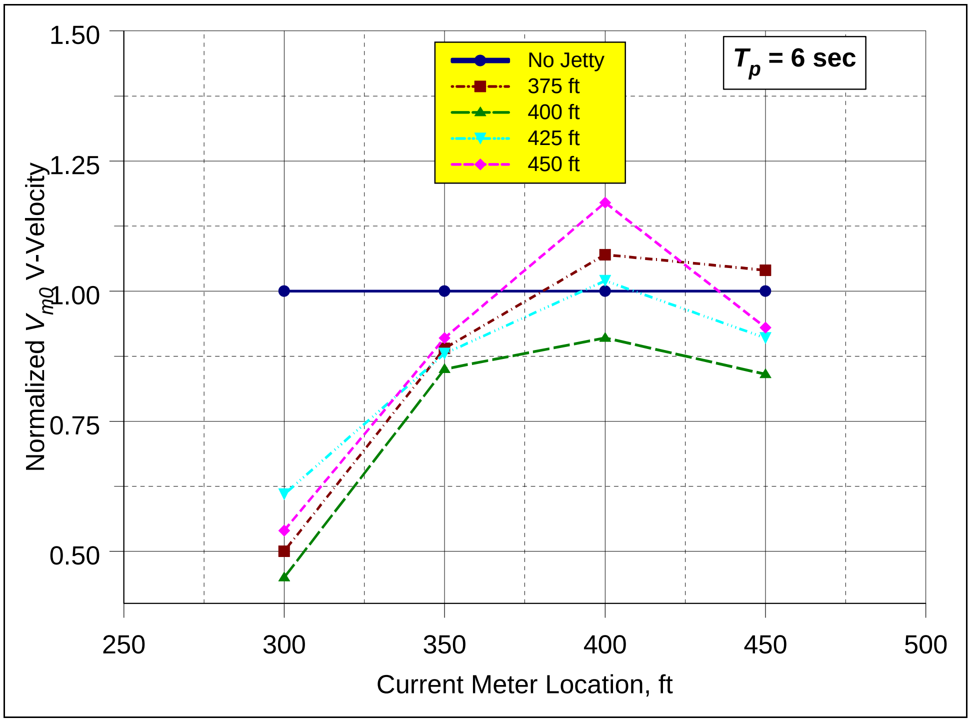



(a) Even analysis for all wave cases and all current meter locations.

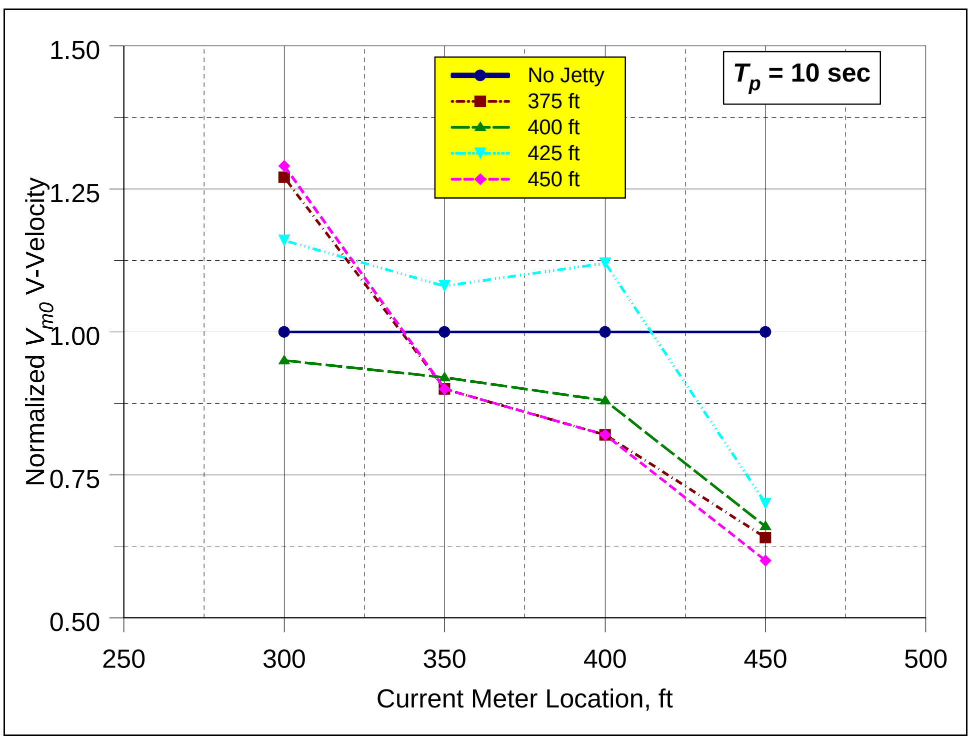



(b) Odd analysis for all wave cases and all current meter locations.

Figure 31. Even-odd analysis of average $V_{m0}$ magnitude for all wave conditions for five jetty configurations, S25W wave direction, Optimization Phase.

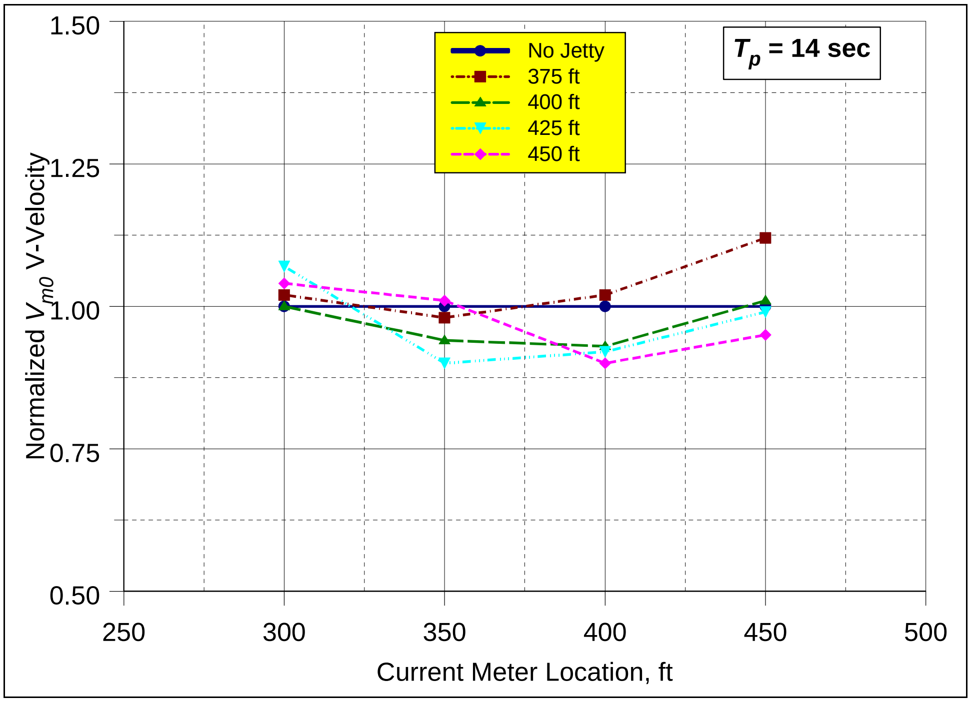



(a) $T_p$ = 6 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

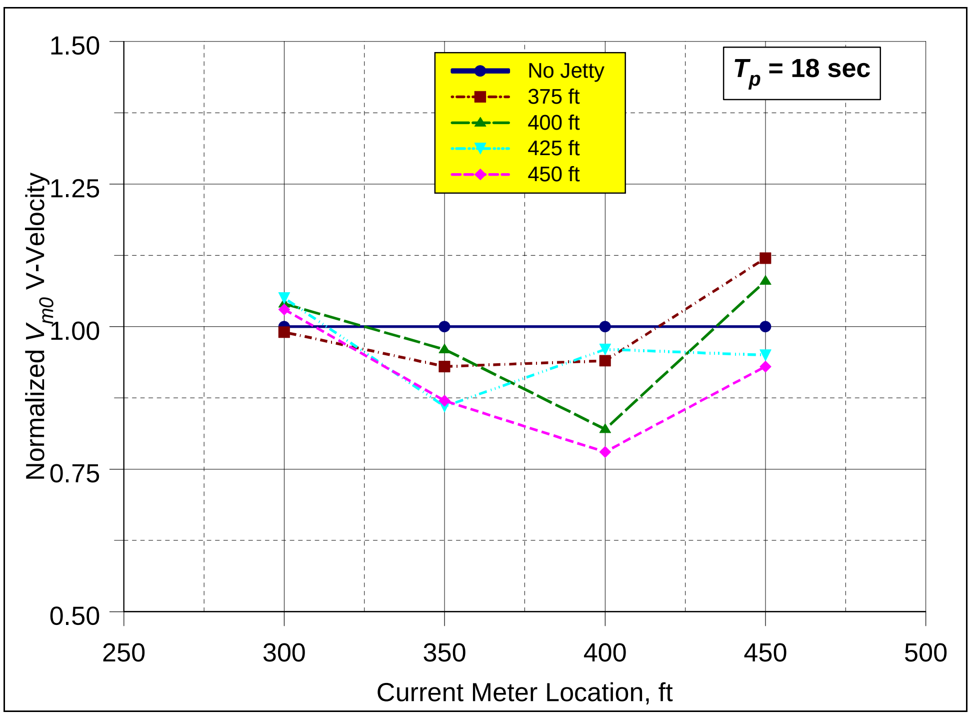



(b) $T_p$ = 10 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

Figure 32. Normalized current *v*-velocity for five jetty configurations, four wave cases, S25W wave direction, Optimization Phase (Continued).

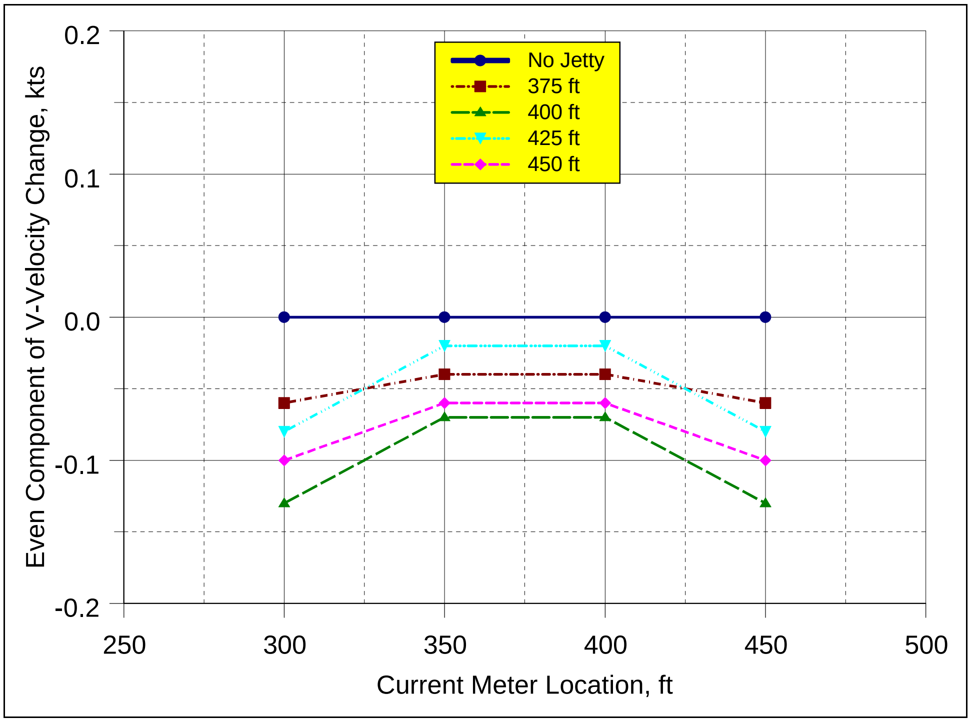



(c) $T_p$ = 14 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

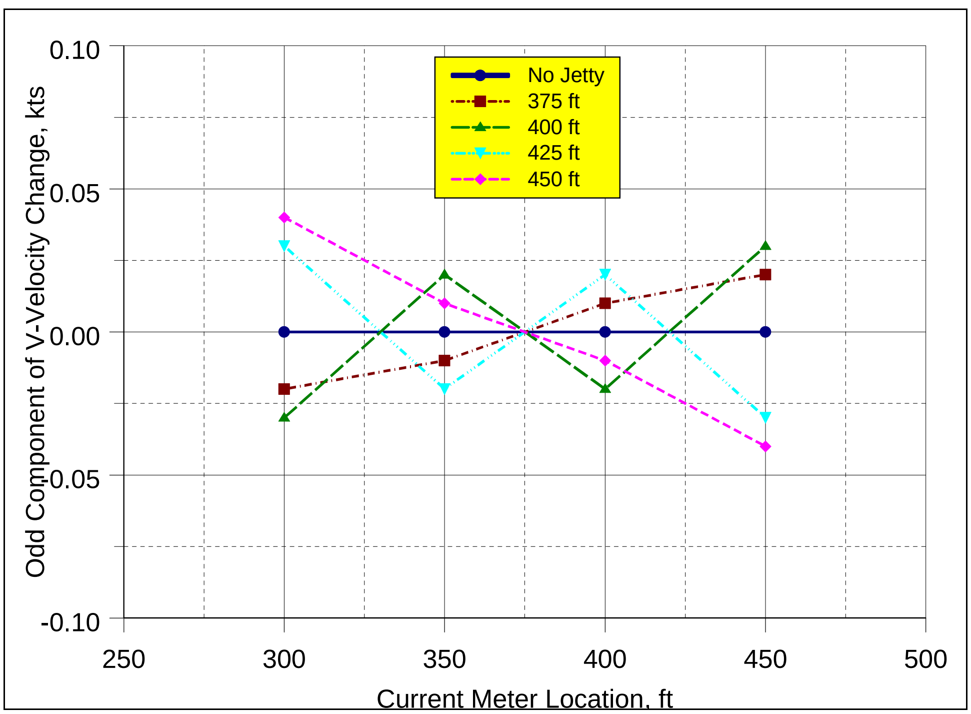



(d) $T_p$ = 18 sec, $x$ = 300, 350, 400 and 450 ft current meter locations.

Figure 32. (Concluded).




(a) Even component analysis for all wave cases.




(b) Odd component analysis for all wave cases.

Figure 33. Even-odd analysis of average *v*-velocity for all wave conditions for five jetty configurations, S25W wave direction, Optimization Phase.

## Ship response

### Vessel speed

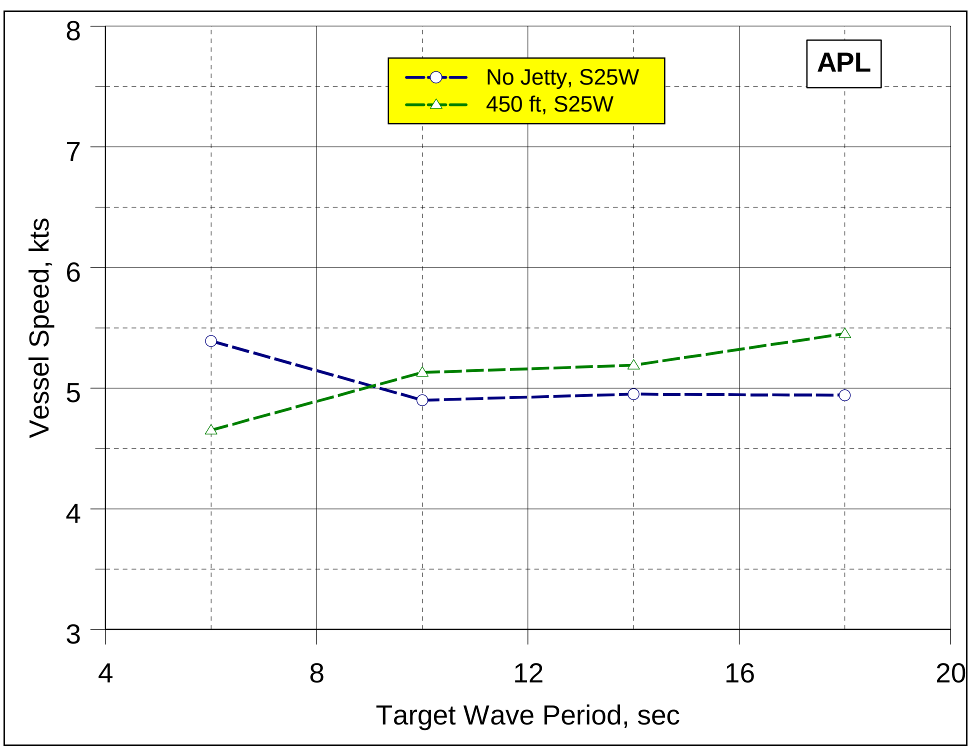
It was anticipated that the vessel speed could vary from the target value during actual tests in waves. Therefore, plans were made to measure the transit times and corresponding ship speeds for each transit. A new set of start/stop lines were located with the offshore line near station 6 and the inshore line near station 34, a distance of 2,816 ft. The inbound and outbound speeds were averaged for each wave condition and vessel. Plots of these speeds versus wave condition are shown in Figure 34. Inbound and outbound ship speeds ranged from 4.3 to 6.7 kts and the barge from 3.1 to 3.9 kts. The average *President Lincoln* speeds ranged from 4.5 to 5.5 kts. Average *Bunga Saga Empat* speeds ranged from 5 to 6 kts. The *Kukahi* barge tow speeds ranged from 3.3 to 4 kts. Appendix J contains tabular listings of inbound, outbound, and average ship speeds for each wave and jetty length combination.

### Vessel response to shear currents

Table 8 is a summary of shear current or current reversals in the vicinity of the proposed jetty for different peak wave periods, wave directions, and jetty lengths. These locations are referenced relative to the shoreline with positive distances measured offshore. Each value represents a location where a shear current, current reversal, or change in current magnitude occurs. They tend to move in time and space along the entrance channel for the different wave periods and jetty lengths (see Table 7). These shears and crosscurrents can provide some difficulty with ship navigation in the range where they occur.

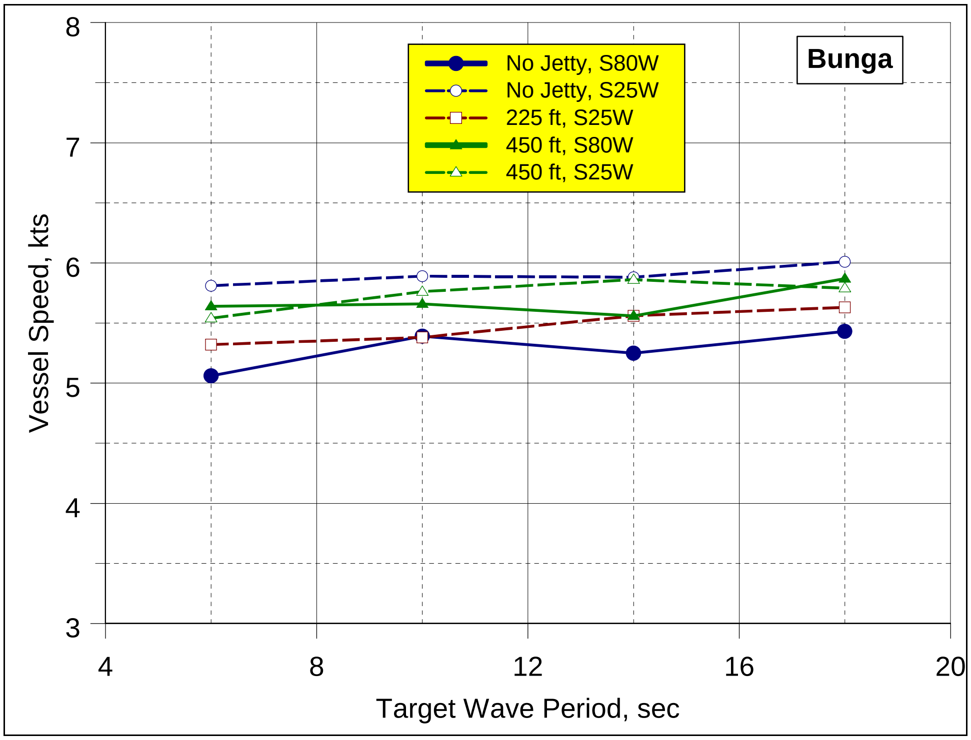
Table 8. Wave-induced shear current summary.

| Jetty Length, ft | Peak Wave Period, sec | | | |
|---|---|---|---|---|
| | 6 | 10 | 14 | 18 |
| S80W Wave Direction | | | | |
| None | 225 | 225, 450 | 225 | 225 |
| 225 | 225, 325 | 150-225, 450 | 150-225 | 225 |
| 450 | 200-300 | 200-250 | 150, 225-250, 325, 350-425 | 225-250, 350 |
| S25W Wave Direction | | | | |
| None | 225, 450 | 225-300 | 225-300 | 150-350 |
| 225 | 225 | 225 | 225 | 325 |
| 300 | | | | |
| 375 | 150, 375 | | | |
| 450 | 150-225, 275-300 | 150-225 | 225 | |
| S25W Wave Direction – Jetty on South Side of Channel | | | | |
| South 225 | | | | |
| South 450 | | | 450 | |
| Notes:<br>1. Values correspond to offshore distances in feet from shoreline with 0 = shore | | | | |

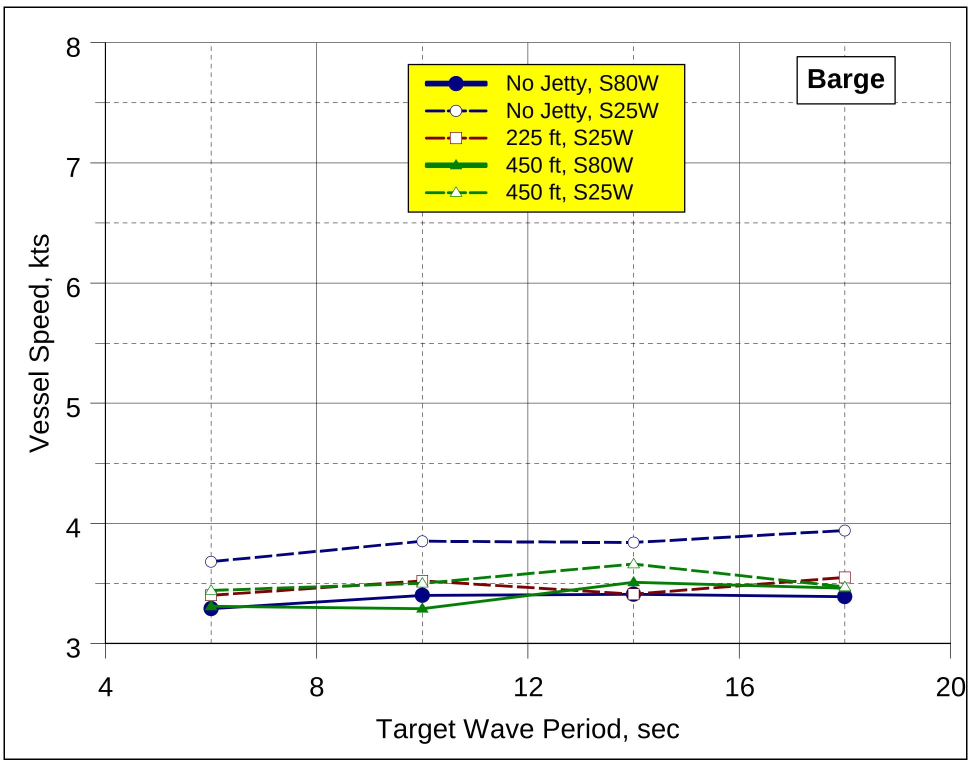



(a) *President Lincoln* ship speeds for S25W wave direction.

Figure 34. Measured ship speeds during Production Phase (Continued).




(b) *Bunga Saga Empat* ship speeds for S80W and S25W wave directions.




(c) *Kukahi* barge ship speeds for S80W and S25W wave directions.

Figure 34. (Concluded).

Table 9 gives a similar summary for the vessel response to the current conditions listed in the previous table. Since the *President Lincoln* is the most streamlined ship, it responded more to the waves. In the Production Phase, it experienced rolling during the inbound, S80W, $T_p$ = 18 sec case with no-jetty. A jetty should afford some protection during incoming runs for this vessel.

The *Bunga Saga Empat* is a blockier vessel and did not experience as noticeable rolling. It was affected more by sway from the crosscurrents. During the Pilot Phase, the *Bunga Saga Empat* grounded on the west side of the channel on an incoming run. On another run, it was left adrift on the channel centerline (i.e., no power to the propeller) to see what effect the wave-induced currents would have the ship motions. The crosscurrents pushed the ship gradually to the west side of the channel. In the Production Phase, it grounded on an armor stone from the jetty that had been dislodged and rolled into the channel. Of course, this is not likely to happen in real life, but it illustrates that the 5-ft underkeel clearance is not overly conservative when wave-induced motions and ship squat are considered.

The *Kukahi* barge, however, did experience many problems with sway and yaw that caused it to meander all over the width of the channel. During the Production Phase, it grounded during a S80W, $T_p$ = 14 sec wave with a 225-ft-long jetty. For the S25W wave direction, it experienced considerable sway from 0 to 225 ft in the channel for the no-jetty condition. There was some evidence of sway even with the 450-ft-long jetty, although the sway was more uniform than for the no-jetty configuration. In general, the jetty did provide needed shelter for the *Kukahi* barge, but more so with waves from the S80W wave direction.

Table 9. Vessel response summary.

| Jetty Length, ft | Vessel | Peak Wave Period, sec | | | |
|---|---|---|---|---|---|
| | | 6 | 10 | 14 | 18 |
| S80W Wave Direction | | | | | |
| None | *President Lincoln* | | | | R0-450 |
| | *Bunga Saga Empat* | | | | |
| | *Kukahi* | N/A | N/A | N/A | N/A |
| 225 | *President Lincoln* | | | | |
| | *Bunga Saga Empat* | | | | GR225 |
| | *Kukahi* | | | GS225 | |
| 450 | *President Lincoln* | | | | |
| | *Bunga Saga Empat* | | | | |
| | *Kukahi* | | | | |
| S25W Wave Direction | | | | | |
| None | *President Lincoln* | | | | |
| | *Bunga Saga Empat* | | | | GMC |
| | *Kukahi* | | SW0-225 | | |
| 450 | *President Lincoln* | | | | |
| | *Bunga Saga Empat* | SW0-225, NSW0-225 | | | |
| | *Kukahi* | | | SW0-225 | |
| 225S | *Bunga Saga Empat* | | | | |
| 450S | *Bunga Saga Empat* | | | | |

Notes:
1. R = roll in this range.
2. SW = sway to west in this range.
3. NSW = sway to west in this range with no speed.
4. GMC = grounded at mid-channel on west side.
5. GR = grounded near seaward end of jetty by dislodged jetty armor stone on bottom of channel.
6. GS = grounded near seaward end of jetty by westward flowing current.

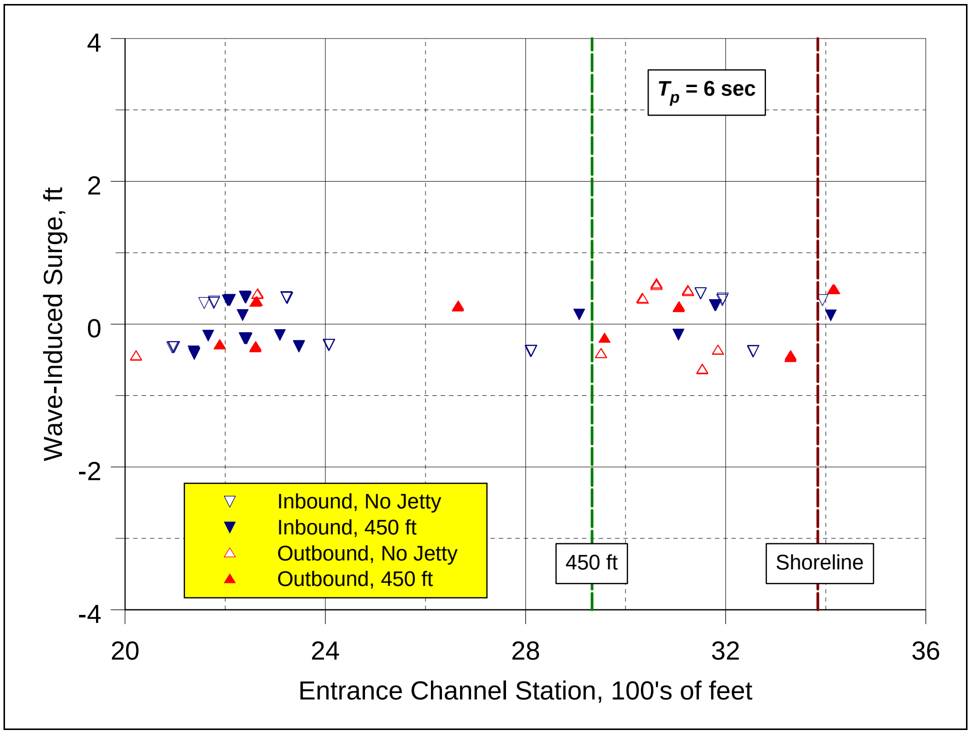
### MOTAN response

Inshore and offshore start/stop lines were located across the entrance channel for measuring ship motions using the MOTAN system. The inshore start/stop line was located near the shoreline at station 34 and the offshore line near station 20. The offshore distance was selected since it was approximately one ship length beyond the head of the proposed jetty. The beginning and ending times for each transit were recorded as the model ship crossed these start/stop lines. The ship's stern was used as the reference for inbound transits and the bow for outbound transits.

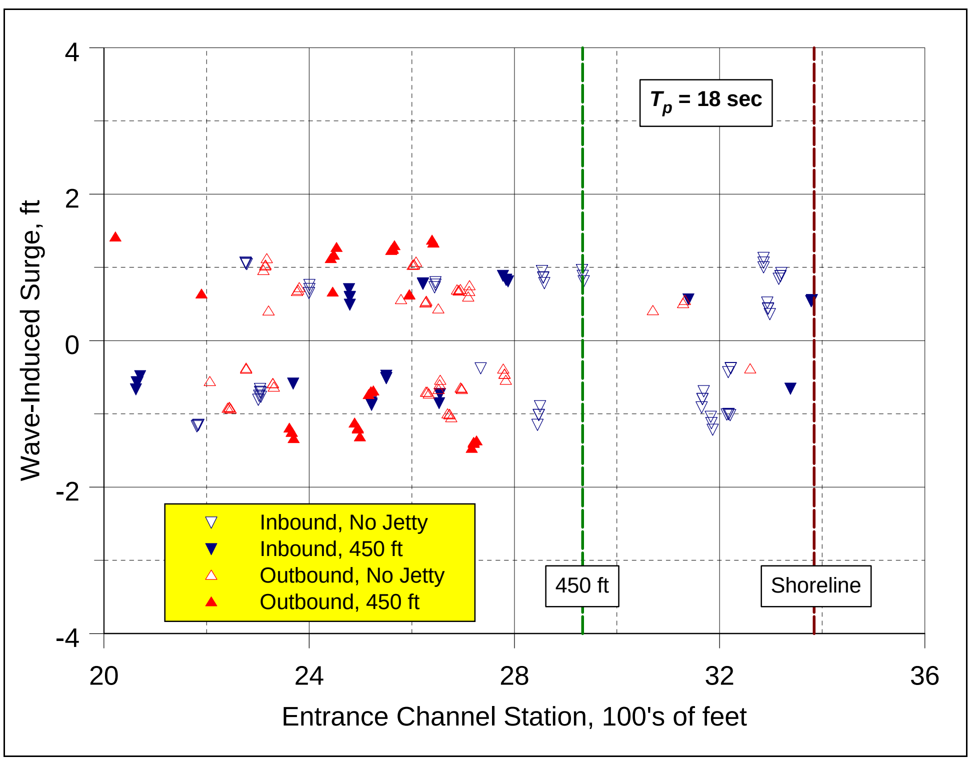
Figures 35 to 40 illustrate the wave-induced motions for the *President Lincoln* for inbound and outbound runs for the no-jetty and 450-ft-long jetty configurations for $T_p$ = 6 and 18 sec. The top panel in each figure is the smaller wave period. These data represent the maximum wave-induced motions for each of the 6DOF measured at the bow and stern centerlines, and the port and starboard sides. The entrance channel station is the location of these maxima. The shoreline and 450-ft distance offshore are shown for reference on each figure. The wave-induced motions tend to increase with wave period. Some larger motions do occur with the 450-ft-long jetty, but they are further offshore than for the no-jetty configuration. In general, there are very little significant differences between the no-jetty and the 450-ft-long jetty configuration for the *President Lincoln*. Since waves are a random process, the location of these maxima is a random process as well. Maxima locations for subsequent runs might be in completely different locations. These data are based on a relatively limited set of 16 or 32 runs for each wave condition, transit direction, and jetty length combination.

## Sponsor and pilot input

Based on study results and the Progress Review Meeting, the consensus was that at least a 375-ft-long jetty was required. This jetty length was based on (a) the handling of the model ships for the different wave conditions and jetty lengths tested, (b) the expert opinion of the Hawaiian pilots, and (c) circulation patterns in the channel and relative magnitudes of crosscurrents.

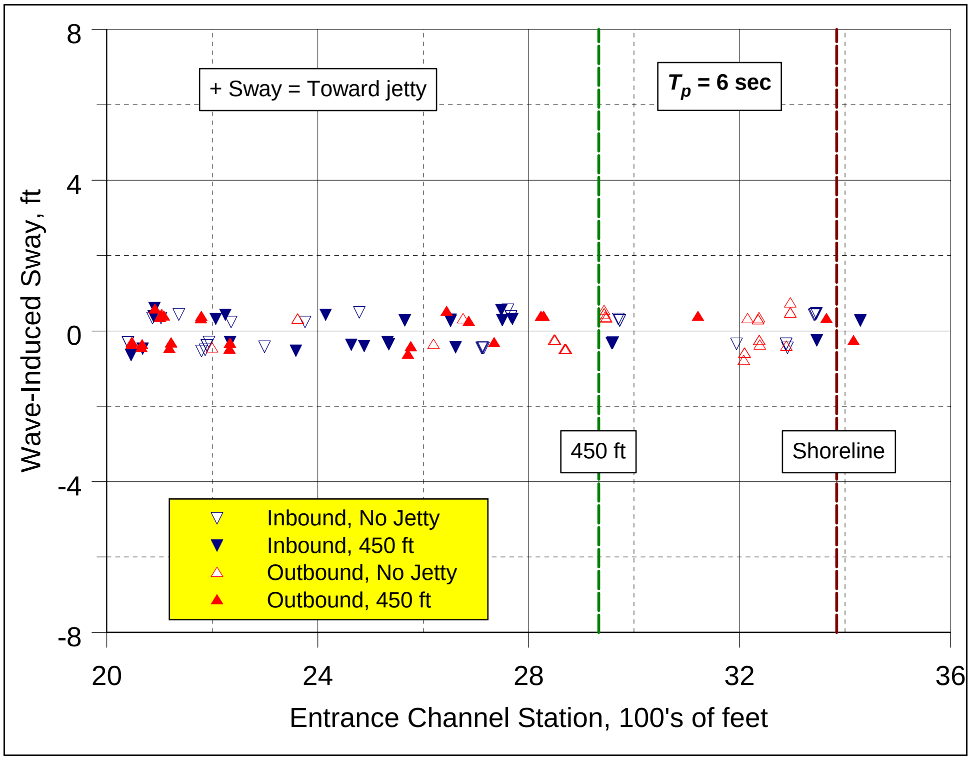



(a) $T_p$ = 6 sec, S25W wave direction.

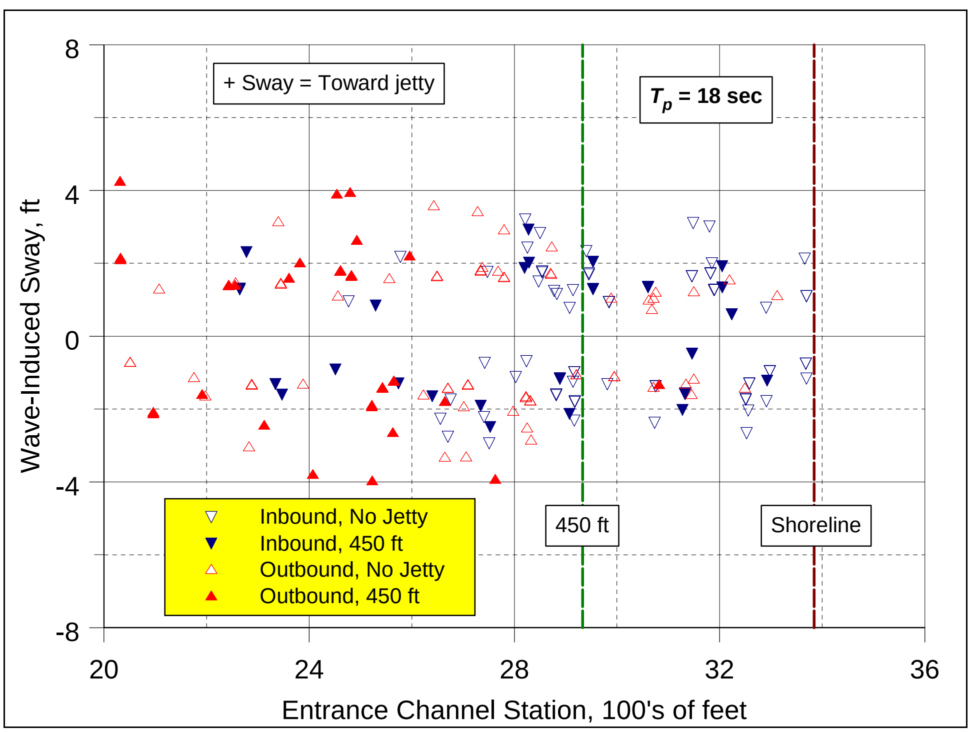



(b) $T_p$ = 18 sec, S25W wave direction.

Figure 35. Wave-induced surge for *President Lincoln* for inbound and outbound runs, no-jetty and 450-ft-long jetty configurations.

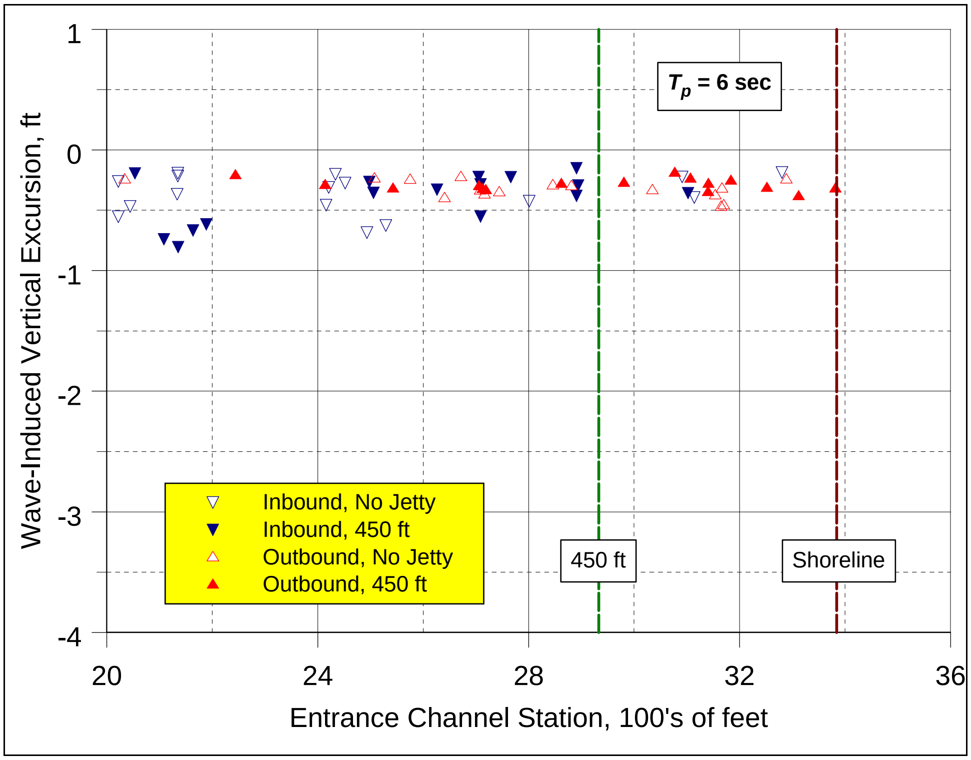



(a) $T_p$ = 6 sec, S25W wave direction.

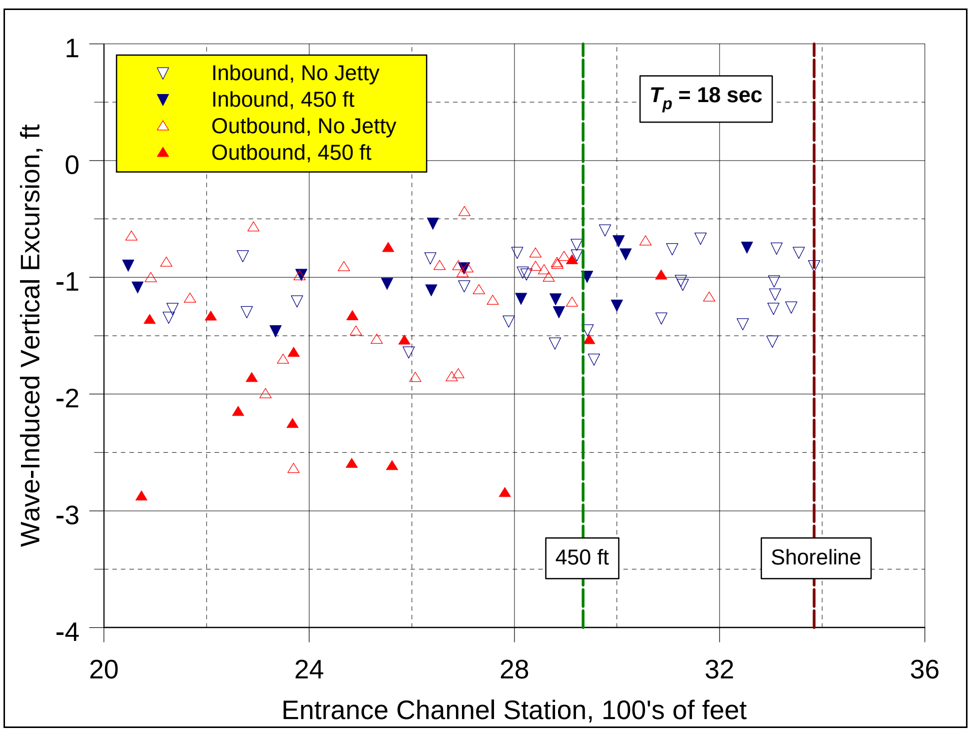



(b) $T_p$ = 18 sec, S25W wave direction.

Figure 36. Wave-induced sway for *President Lincoln* for inbound and outbound runs, no-jetty and 450-ft-long jetty configurations.

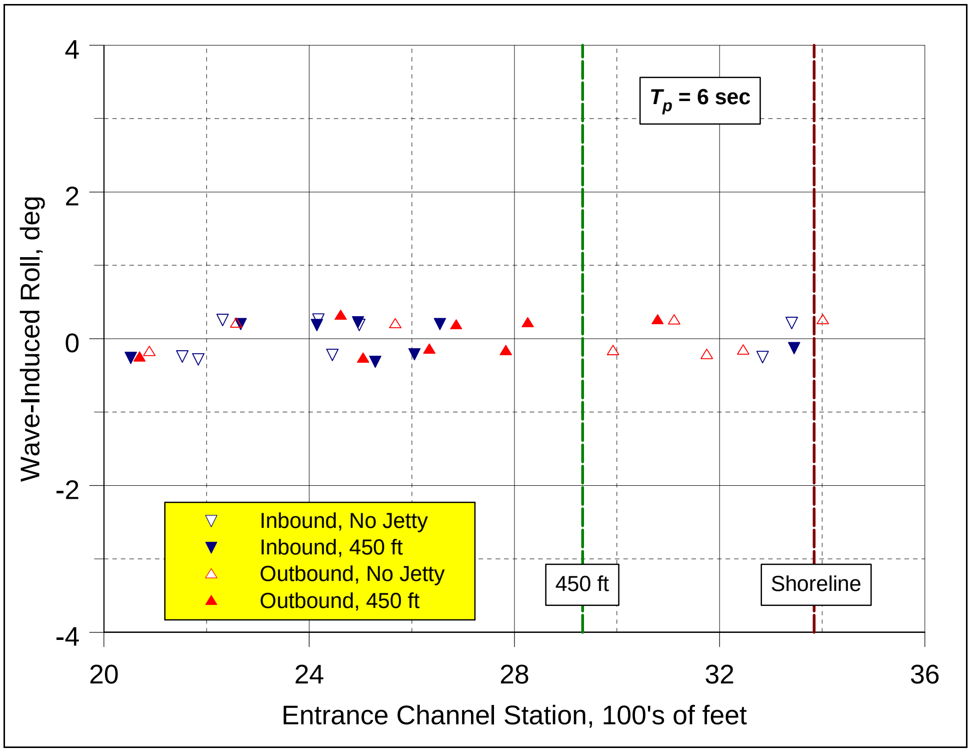



(a) $T_p$ = 6 sec, S25W wave direction.

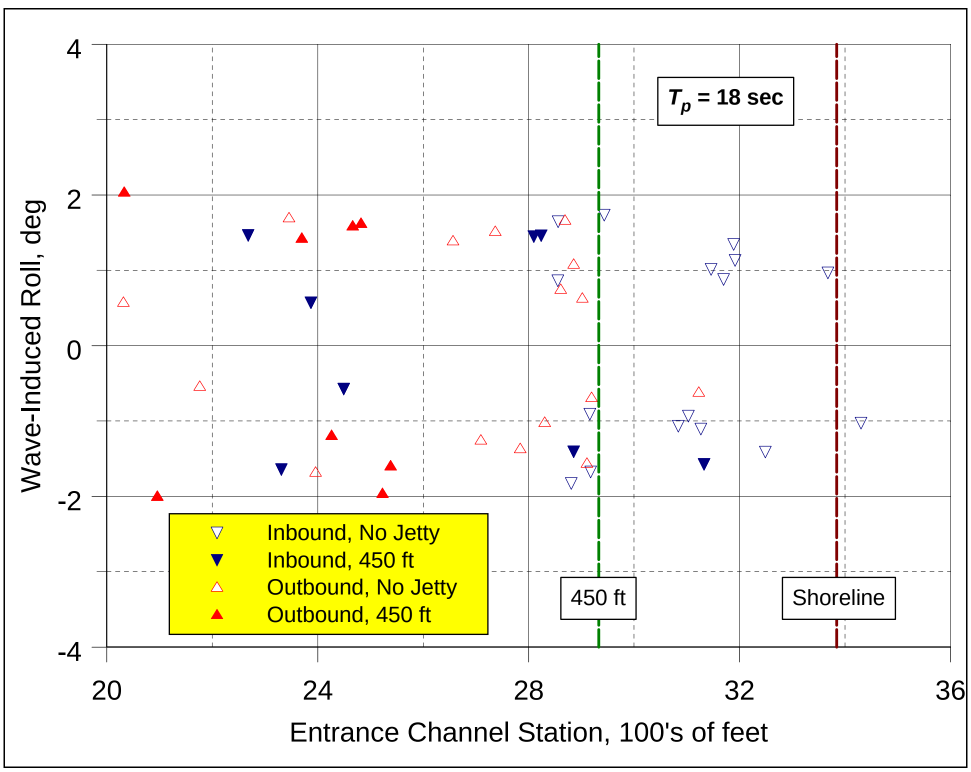



(b) $T_p$ = 18 sec, S25W wave direction.

Figure 37. Wave-induced vertical excursion for *President Lincoln* for inbound and outbound runs, no-jetty and 450-ft-long jetty configurations.

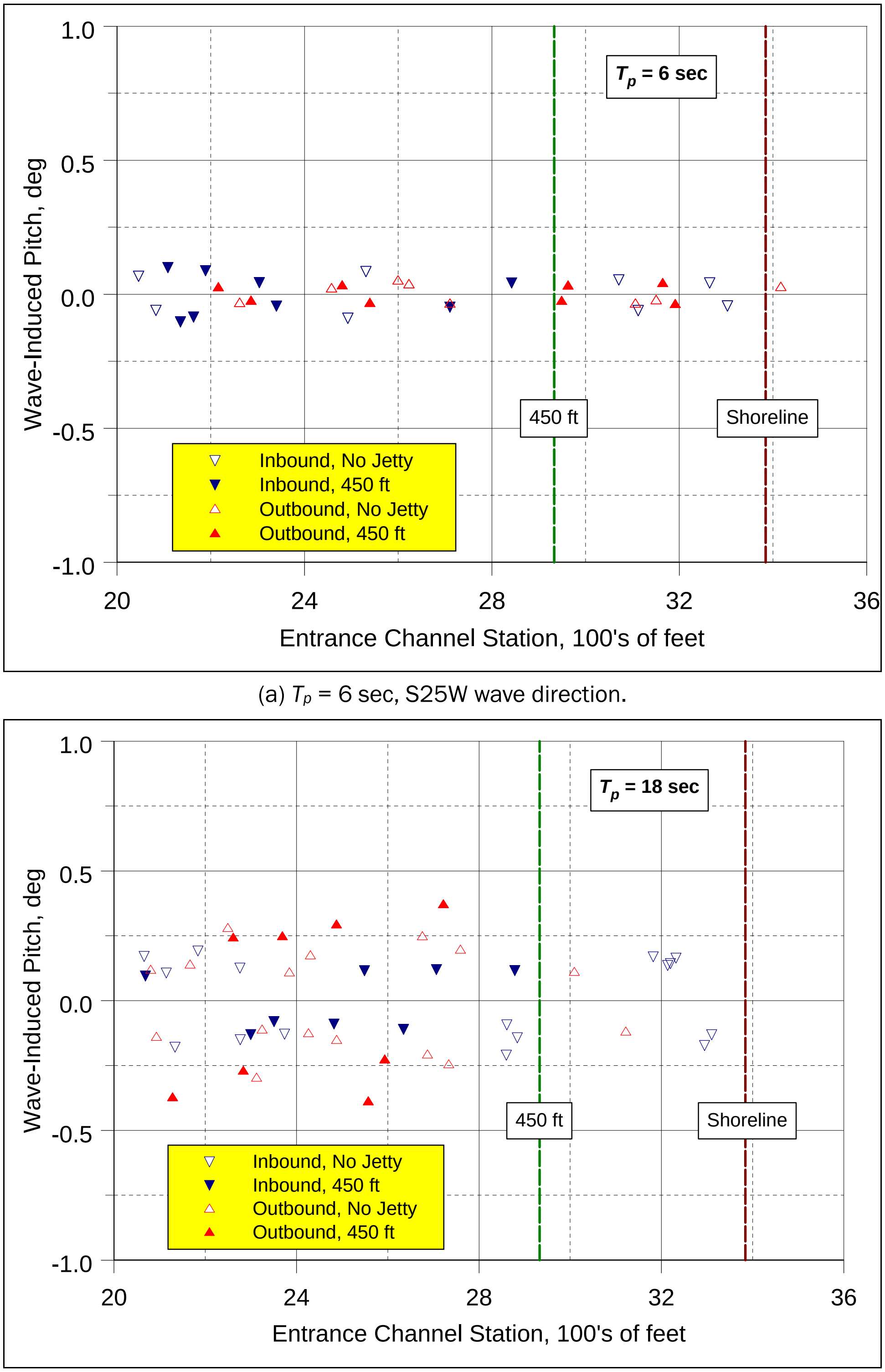



(a) $T_p$ = 6 sec, S25W wave direction.




(b) $T_p$ = 18 sec, S25W wave direction.

Figure 38. Wave-induced roll for *President Lincoln* for inbound and outbound runs, no-jetty and 450-ft-long jetty configurations.

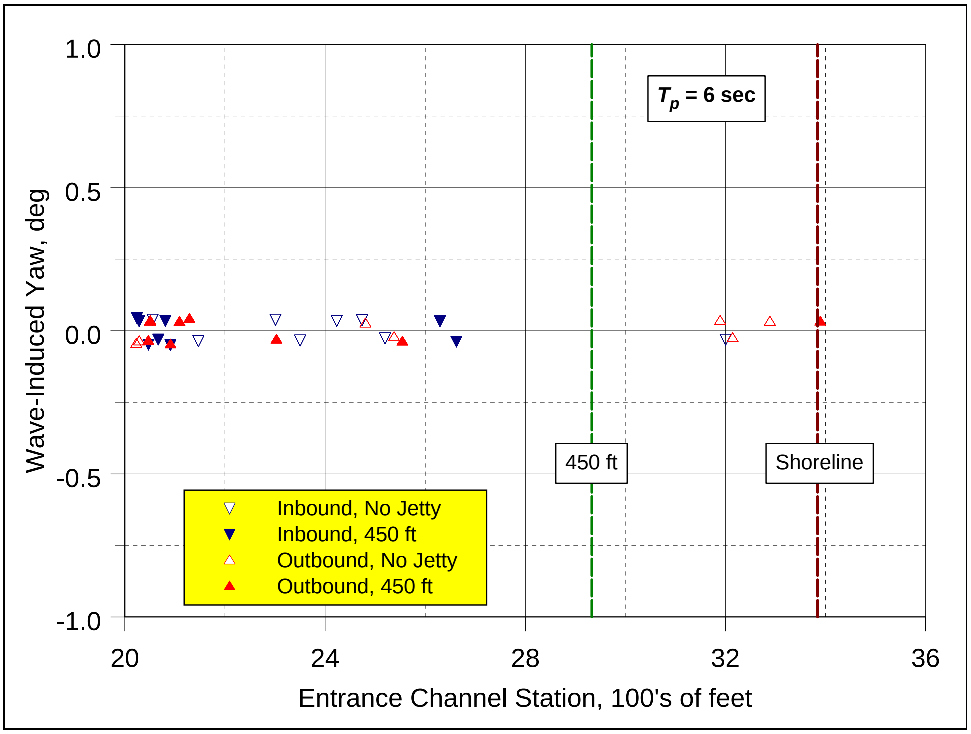



(a) $T_p$ = 6 sec, S25W wave direction.

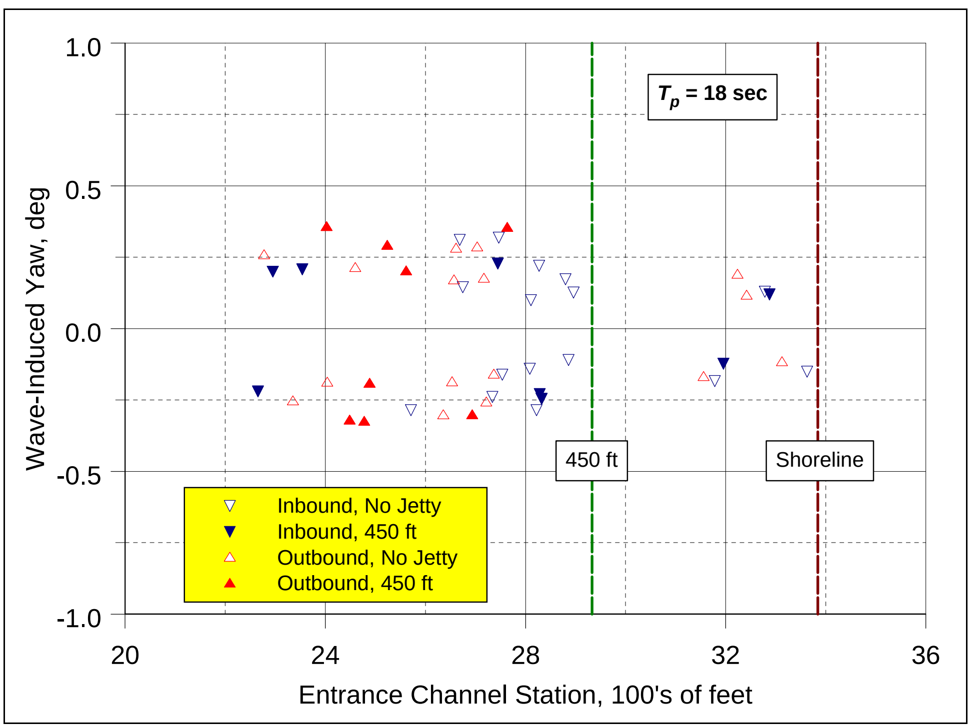


(b) $T_p$ = 18 sec, S25W wave direction.

Figure 39. Wave-induced pitch for *President Lincoln* for inbound and outbound runs, no-jetty and 450-ft-long jetty configurations.




(a) $T_p$ = 6 sec, S25W wave direction.




(b) $T_p$ = 18 sec, S25W wave direction.

Figure 40. Wave-induced yaw for *President Lincoln* for inbound and outbound runs, no-jetty and 450-ft-long jetty configurations.

# 6 Summary and Conclusions

Based on results for the wave conditions and jetty lengths studied, the 375-ft-long jetty and the 2-ft depth transition inside the harbor are recommended. The distance from the old transition at the shoreline to the new transition in the harbor is approximately equal to a ship length. Thus, the effect of the shear on the ship as it moves over the abrupt vertical change in bottom elevation is minimized by moving this transition back into the harbor. The combination of the 375-ft jetty and modified location and height of the channel transition will provide sufficient sheltering from the waves and currents near the shoreline. This conclusion is based on (a) measured wave heights in the channel and barge basin, (b) ship and barge handling and maneuverability characteristics, (c) dye and current meter studies of the circulation patterns in the channel, (d) input from the sponsor, EPA, and (e) expert opinion from the harbor pilots. The previous studies by Briggs et al. (1994) and Harkins and Dorrell (2000) also support this recommendation to provide safe navigation conditions in the entrance channel.

The Optimization Phase was conducted to determine if this 375-ft jetty length could be optimized further. Previously, only jetty lengths of 225, 300, 375, and 450 ft had been studied. Thus, jetty lengths of 375, 400, 425, and 450 ft were investigated to fill in the gaps between jetty lengths of 375 and 450 ft. Current magnitudes, cross-channel velocity components, and magnitude differences relative to the no-jetty configuration were calculated for the four current meter locations in the entrance channel. Current magnitudes were between 1 to 2 kts. The direction was more “to and fro” aligned with the wave direction for the smaller wave period of $T_p$ = 6 sec and turned more westerly and normal to the channel centerline as the wave period increased.

In general, there was very little variation in wave height or current magnitude and direction as a function of wave period, jetty length, and location. There was no clear-cut “winner” based on the jetty configurations tested in this study. Some jetty lengths were slightly better than others for different wave periods and locations in the channel. The input from the harbor pilots was instrumental in selecting a minimum jetty length of 375 ft, based on the ship and barge responses. In combination with the modified depth transition, the shorter 375-ft-long jetty will provide the needed navigation sheltering from waves and currents, with minimal construction costs and impact on the environment.

# References

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# Appendix A: Vessel Weight Distributions

Table A1. APL *President Lincoln* weight distribution (see photographs).

| Hold | Row | Weight | | Shape | Comment |
|---|---|---|---|---|---|
| | | ID | lb | | |
| 1 | | 1 | 4.70 | | |
| | | 2 | 4.70 | | |
| | B | 75 | 4.88 | | |
| | S | 76 | 5.12 | | |
| 2 | | 3 | 4.96 | | |
| | | 4&5 | 9.46 | | |
| 3 | | 6 | 10.40 | | |
| | | 7 | 10.40 | | |
| | | 8 | 5.08 | | |
| | | 55 | 4.81 | | |
| 4 | | 9 | 15.04 | | |
| | | 10top | 4.72 | | Top |
| | | 10bot | 4.60 | | Bottom |
| | | 11 | 15.20 | | |
| | PB | 20 | 4.69 | | |
| | SB | 38 | 4.75 | | |
| | PS | 73 | 4.92 | | |
| | SS | 74 | 4.68 | | |
| | SM | 40 | | | Remove for MOTAN |
| | PM | 49 | | | Remove for MOTAN |
| | | | 11.21 | | MOTAN LogBook, etc. |
| 5 | S | 12s | 5.10 | | Starboard |
| | P | 12p | 4.96 | | Port |
| | PB | 96 | | R | Remove for MOTAN, top of 99 |
| | PB | 99 | 3.19 | R | |
| | SB | 138 | | R | Remove for MOTAN, top of 144 |
| | SB | 144 | | R | Remove for MOTAN |
| | PS | 39 | 3.22 | R | |
| | SS | 130 | 3.21 | R | MOTAN |
| | | | 7.08 | | MOTAN Sensor/Plywood |
| 6 | | 13 | 10.02 | | |
| | | 14 | 9.74 | | |
| | MB | 6 | 3.26 | R | Top of 36 |
| | MS | 36 | 3.24 | R | |
| | | 124 | 3.23 | R | Top of 133 |
| | | 133 | 3.17 | R | |
| 7 | | Battery | 13.26 | | |
| Total: | | | 206.99 | | |

Notes:
1. Row codes show orientation in hold: 1st Character: P=Port, S=Starboard, M=Middle
2. Row codes show orientation in hold: 2nd Character: B=Bow, M=Middle, S=Stern
3. R=Round weight, all others rectangular
4. Ship run with and without MOTAN (Motion Analysis System) for measuring ship 6 DOF motions
5. MOTAN system used in another study, so weight included here for proper ballasting of ship. Remove weights if use MOTAN system

Table A2. APL miscellaneous weights.

| Hold | Name | ID | Weight, lb |
|---|---|---|---|
| Hatch Covers | | | |
| 1&2 | Bow | B1-2 | 0.98 |
| 3 | Forward | B3 | 1.14 |
| 4 | Middle | B4 | 1.78 |
| 5 | Stern | B5 | 1.28 |
| 6 | Motor | B6 | 1.16 |
| 7 | Battery | B7 | 1.12 |
| Subtotal: | | | 7.46 |
| Foam | | | |
| 1 | Bow | | 0.04 |
| 2 | Bow | | 0.06 |
| 3 | Forward | | 0.28 |
| 4, Level 1 | Middle | | 0.42 |
| 4, Level 2 | Middle | | 0.60 |
| 5 | Stern | | 0.38 |
| 6 | Motor | | 0.32 |
| Subtotal: | | | 2.10 |
| Total: | | | 21.58 |

Notes:
1. ID: Hatch covers labeled with code B + Hold number
2. Two levels in hold 4, level 1 on top of level 2

Table A3. *Bunga Saga Empat* weight distribution (see photographs).

| Hold | Row | Weight ID | Weight lb | Shape | Comment |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 4.84 | | |
| | | 2 | 4.84 | | |
| | | 3 | 4.97 | | |
| | | 4 | 4.97 | | |
| | | 5 | 5.00 | | |
| | 2 | 6 | 5.00 | | |
| | | 7 | 4.81 | | |
| | | 8 | 4.81 | | |
| | | 9 | 4.75 | | |
| | | 10 | 4.78 | | |
| 2 | 1 | 11 | 5.06 | | |
| | | 12 | 4.75 | | |
| | | 13 | 5.00 | | |
| | | 14 | 4.75 | | |
| | 2 | 15 | 5.00 | | |
| | | 16 | 4.69 | | |
| | | 17 | 5.06 | | |
| | | 18 | 4.72 | | |
| | 3 | 19 | 5.06 | | |
| | | 22 | 4.63 | | |
| | 4 | 23 | 5.13 | | |
| | | 24 | 4.69 | | |
| | 5 | 25 | 5.06 | | |
| | | 26 | 4.59 | | |
| | | 27 | 5.25 | | |
| | | 28 | 4.56 | | |
| | | 29 | 4.50 | | |
| | 6 | 30 | 4.63 | | |
| | | 31 | 5.13 | | |
| | | 32 | 5.06 | | |
| | | 33 | 4.63 | | |
| 3 | 1 | 34 | 4.69 | | |
| | | 35 | 5.06 | | Remove for MOTAN |
| | | 36 | 5.06 | | Remove for MOTAN |
| | | 37 | 4.69 | | |
| | 3 | 39 | 4.75 | | |
| | 2 | 41 | 4.75 | | |
| | | 42 | 5.06 | | |
| | | 43 | 4.94 | | |
| | | 44 | 4.94 | | |
| | | 45 | 4.94 | | |
| 4 | 1 | 46 | 4.94 | | Remove for MOTAN |
| | | 48 | 4.94 | | |
| | | 50 | 4.84 | | Remove for MOTAN |
| | 2 | 52 | 4.75 | | |
| | | 53 | 4.81 | | |
| | | 54 | 4.88 | | |

| Hold | Row | Weight | | Shape | Comment |
|---|---|---|---|---|---|
| | | ID | lb | | |
| Battery | 1 | Battery | 39.50 | | New, replace old battery |
| | | Straps | 0.72 | | Straps + bolts |
| | | 71 | 15.88 | | Total: 71, 72, 51, 33 |
| | | 72 | | | Weights 71, 72, 51, 33 added |
| | | 51 | | | to offset weight of old battery |
| | | 33 | | R | |
| 5 | 1 | 56 | 4.81 | | |
| | | 57 | 5.00 | | |
| | 2 | 58 | 4.97 | | |
| | | 59 | 4.91 | | |
| 6 | 1 | 60 | 4.97 | | |
| | | 61 | 5.00 | | |
| | 2 | 62 | 4.84 | | |
| | | 63 | 4.94 | | |
| | 3 | 64 | 4.88 | | |
| | | 65 | 4.94 | | |
| **Total:** | | | **334.10** | | |

Notes:
1. Hold 1 closest to bow, 6 closest to stern.
2. Room for 5 columns of weights in each hold.
3. R = Round shape, others rectangular.
4. Ship run with and without MOTAN (Motion Analysis System) for measuring ship 6 DOF motions.
5. MOTAN system used in another study, so weight included here for proper ballasting of ship. Remove weights if use MOTAN system.

Table A4. *Kukahi* barge weight distribution.

| Hold | Row | Weight | | Shape | Comment |
|---|---|---|---|---|---|
| | | ID | lb | | |
| 1 | PB | 57 | 1.18 | Round | |
| | SB | 10 | 1.20 | | |
| | MS | Battery | | Rectangle | Tow boat |
| 2 | PB | 66 | 3.19 | Round | |
| | PS | 98 | 3.17 | | |
| | SB | 62 | 3.20 | | |
| | SS | 108 | 3.17 | | |
| 3 | PS | 60 | 3.24 | | |
| | SS | 61 | 3.23 | | |
| **Total:** | | | **21.58** | | |

Notes:
1. ID, 1st Col: P=Port, S=Starboard
2. ID: 2nd Col: B=Bow, S=Stern

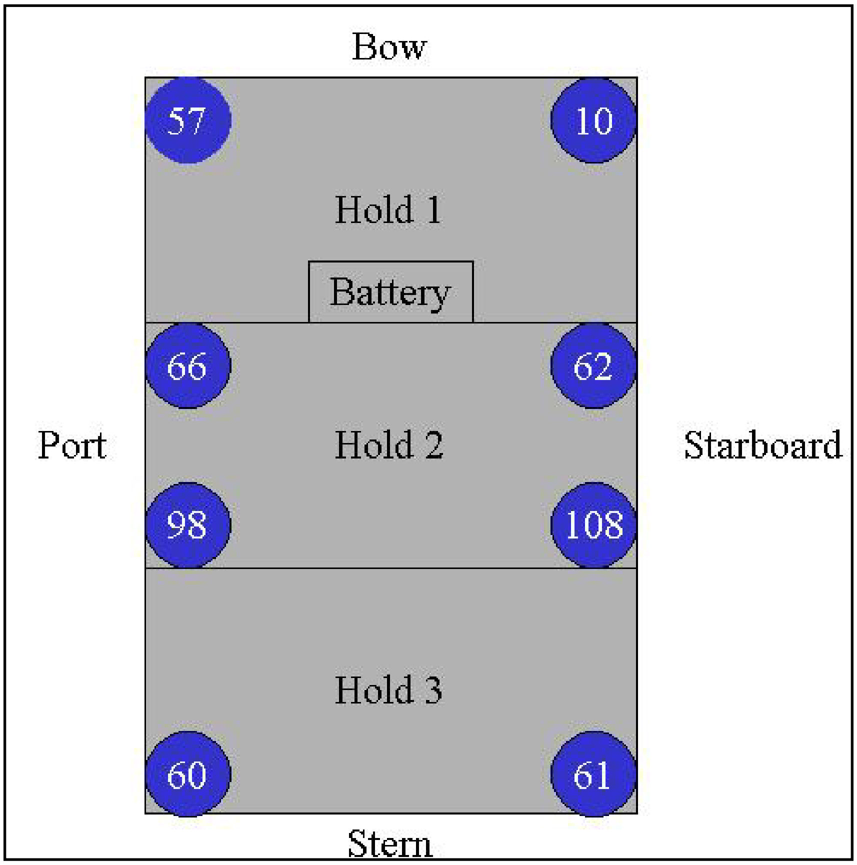



Figure A1. *Kukahi* barge weight distribution.

Table A5. Digital level readings.

| Covers | Orientation | Reading | Direction |
|---|---|---|---|
| APL *President Lincoln* | | | |
| No | Bow-Stern | 0.10 | Up |
| | Port-Starboard | 0.09 | Down |
| Yes | Bow-Stern | 0.12 | Up |
| | Port-Starboard | 0.10 | Down |
| *Bunga Saga Empat* | | | |
| No | Bow-Stern | 0.74 | Down |
| | Port-Starboard | 0.61 | Up |
| Yes | Bow-Stern | 0.73 | Down |
| | Port-Starboard | 0.61 | Up |
| **Total:** | | | 21.58 |
| Notes:<br>1. Orientation = Level orientation on ship stern<br>2. Up = direction arrow points up<br>3. Down = direction arrow points down | | | |

Table A6. Side marker readings for *Bunga Saga Empat*.

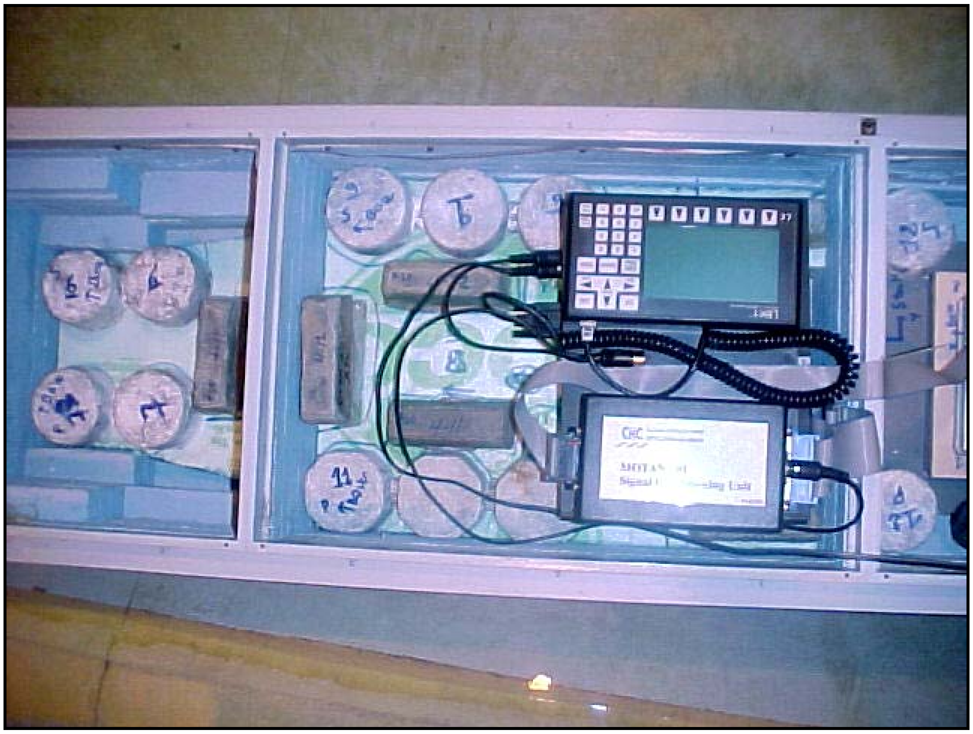
| Covers | Side | Position | cm |
|---|---|---|---|
| Draft zero | | | 50.00 |
| No | Port | Bow | 65.50 |
| | | Stern | 65.50 |
| | Starboard | Bow | 65.70 |
| | | Stern | 65.70 |
| Yes | Port | Bow | 66.00 |
| | | Stern | 66.00 |
| | Starboard | Bow | 66.10 |
| | | Stern | 66.15 |

Notes:
1. Marker rules on sides of ship in 4 locations.
2 Arbitrary units on marker.
3. Use difference for draft.

(a) Mvc-423f, Holds 1 and 2, weights stacked in Hold 1.

(b) Mvc-424f, Hold 3, round and rectangular weights.

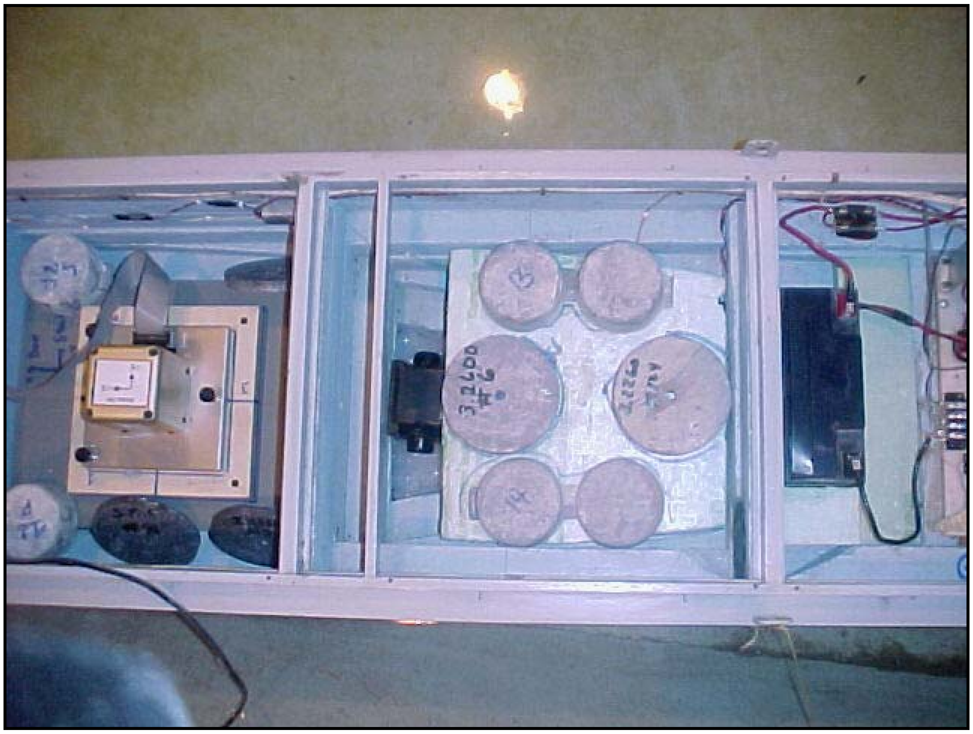
Photo A1. Model ship weight distribution for APL *President Lincoln* with MOTAN motion analysis system, views from port side of ship (see Appendix Tables A1 and A2).



(c) Mvc-425f, Hold 4 with MOTAN components.


(d) Mvc-426f, Hold 5 with MOTAN accelerometer package.

Photo A1. (Continued).



(e) Mvc-427f, Hold 6 with round weights.

(f) Mvc-428f, Hold 7 with battery and electronics for control.

Photo A1. (Concluded).

(a) Mvc-430f, Hold 1, Rows 1 and 2.

(b) Mvc-431f, Hold 2, Rows 1-3, note stair-step arrangement.

Photo A2. Model ship weight distribution for *Bunga Saga Empat* with MOTAN motion analysis system, views from port side of ship (see Appendix Table A3).

(c) Mvc-433f, Close-up of Hold 2, Rows 1-3.

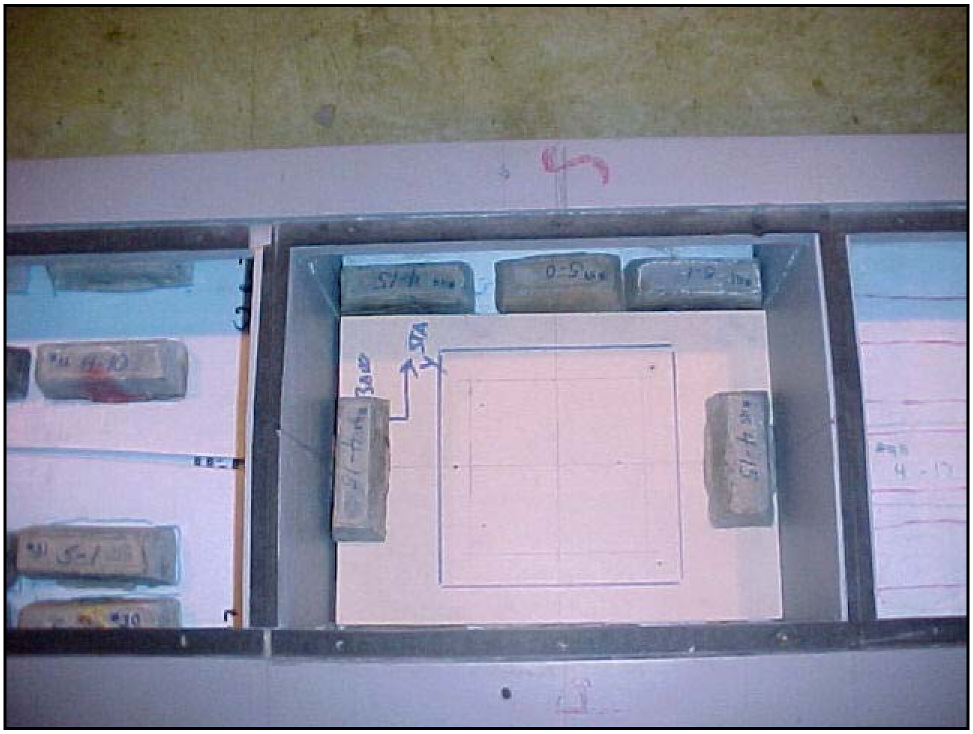
(d) Mvc-432f, Hold 2, Rows 4-6.

Photo A2. (Continued).

(e) Mvc-434f, Close-up of Hold 2, Rows 4-6.

(f) Mvc-441f, Close-up of Hold 2, Rows 4-6, from starboard side.

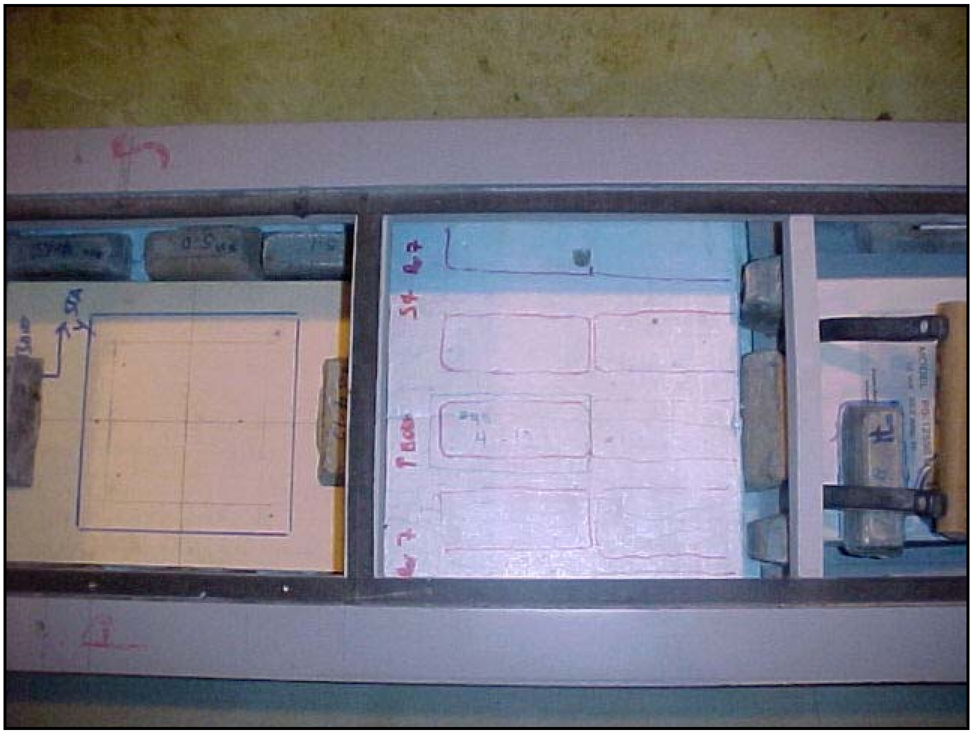
Photo A2. (Continued).



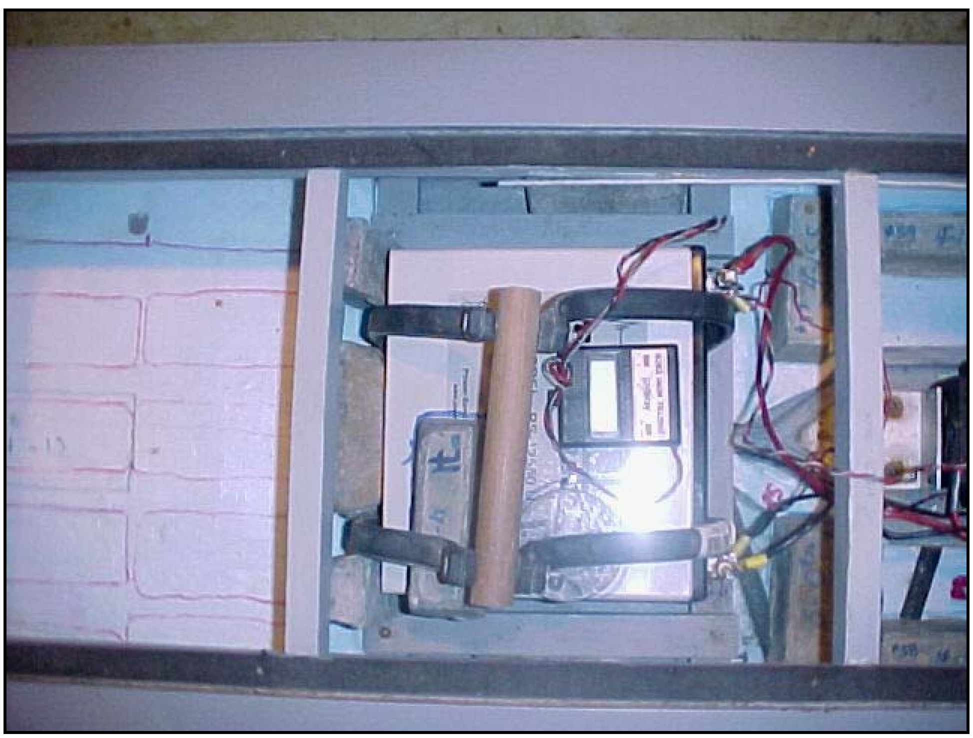

(g) Mvc-435f, Hold 3, MOTAN accelerometer package space.


(h) Mvc-440f, Close-up of Hold 3, MOTAN accelerometer package space, from starboard side of ship.

Photo A2. (Continued).

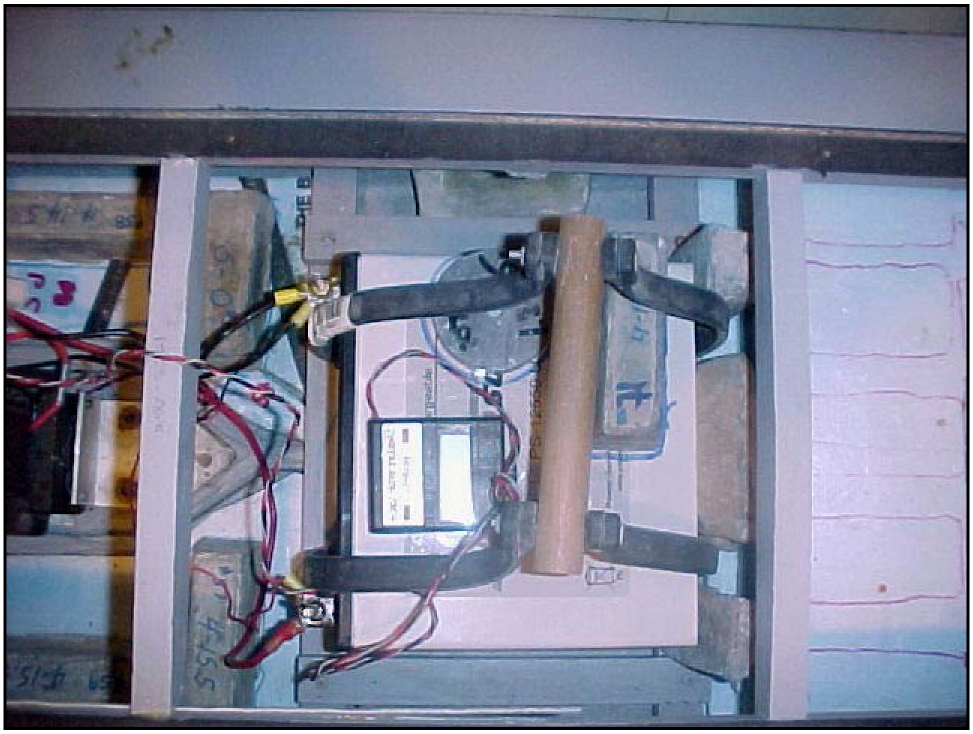


(i) Mvc-436f, Hold 4, weights removed for MOTAN components.

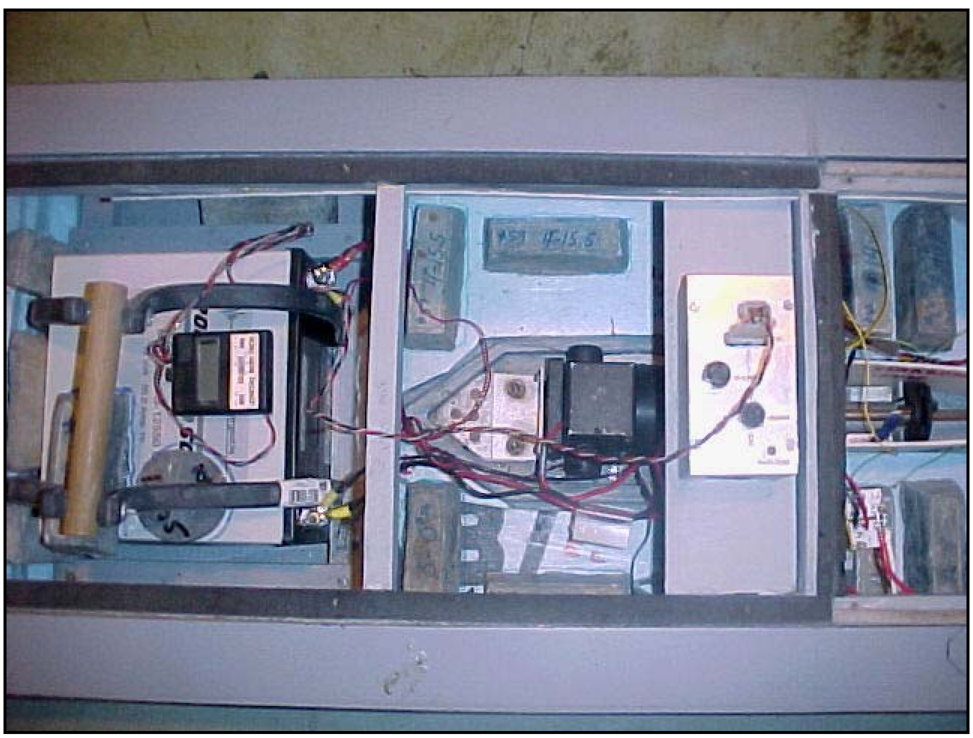


(j) Mvc-437f, Battery compartment.

Photo A2. (Continued).

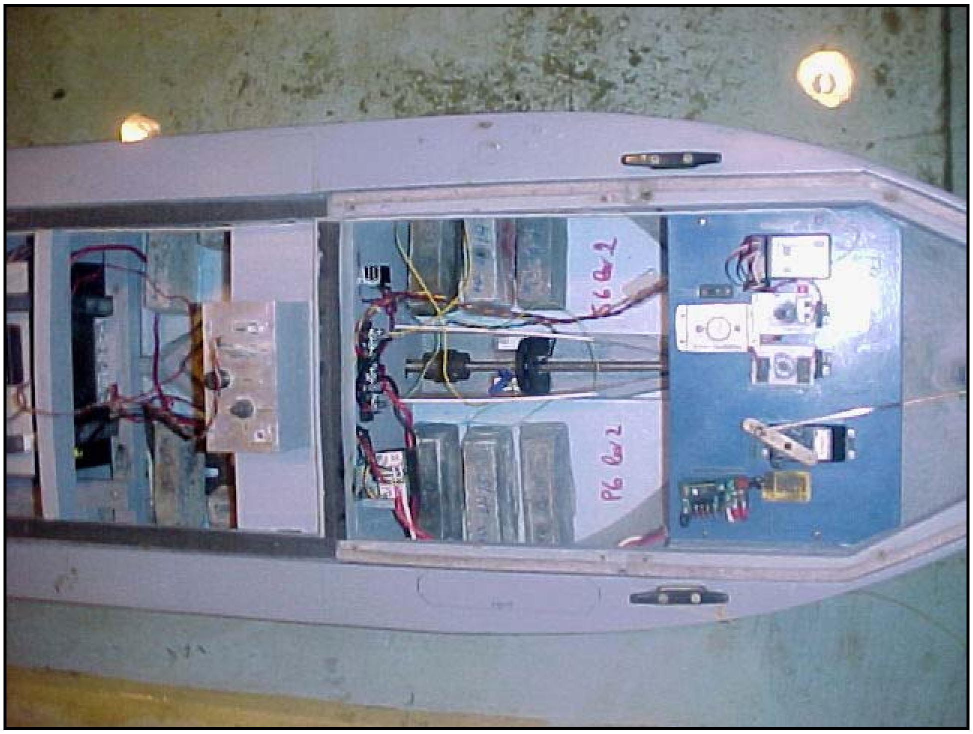


(k) Mvc-443f, Battery compartment, from starboard side of ship.



(l) Mvc-438f, Hold 5 or engine compartment, showing motor and electronics.

Photo A2. (Continued).



(m) Mvc-439f, Hold 6, Rows 1-3 at stern of ship.

Photo A2. (Concluded).

# Appendix B: Calibration Phase Wave Data

Table B1. Calibration Phase wave heights in prototype feet.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Wave Direction S80W (35 deg west) | | | | | | | | | |
| BPJ09 | 6 | No | 6.82 | 7.10 | 6.93 | 7.06 | 6.95 | 7.20 | 5.32 |
| BPJ10 | | | 7.09 | 6.98 | 7.20 | 7.16 | 5.26 | 7.55 | 5.08 |
| BPJ11 | | | 5.65 | 6.74 | 5.77 | 5.83 | 3.94 | 6.54 | 3.54 |
| BPJ12 | | | 4.70 | 7.00 | 5.91 | 4.62 | 3.48 | 7.35 | 3.94 |
| Wave Direction S25W (20 deg south) | | | | | | | | | |
| BPJ09 | 7 | No | 8.25 | 7.06 | 7.11 | 3.87 | 3.34 | 5.21 | 7.26 |
| BPJ10 | | | 8.03 | 7.61 | 7.93 | 3.67 | 2.88 | 5.77 | 6.94 |
| BPJ11 | | | 6.16 | 6.06 | 6.70 | 2.75 | 2.21 | 4.70 | 8.21 |
| BPJ12 | | | 5.62 | 7.21 | 6.02 | 2.20 | 1.75 | 4.37 | 8.48 |
| BPJ09 | 8 | 225 | 8.40 | 7.45 | 7.23 | 3.85 | 3.20 | 5.82 | 7.41 |
| BPJ10 | | | 8.09 | 7.56 | 8.07 | 3.79 | 3.02 | 5.83 | 7.17 |
| BPJ11 | | | 6.23 | 6.12 | 6.77 | 2.91 | 2.35 | 4.81 | 8.40 |
| BPJ12 | | | 5.65 | 7.16 | 6.04 | 2.26 | 1.83 | 4.36 | 8.54 |
| BPJ09 | 9 | 450 | 8.35 | 7.57 | 7.29 | 3.75 | 3.18 | 5.92 | 7.45 |
| BPJ10 | | | 8.09 | 7.66 | 8.12 | 3.81 | 3.03 | 6.02 | 7.25 |
| BPJ11 | | | 6.24 | 6.10 | 6.81 | 2.91 | 2.26 | 5.02 | 8.39 |
| BPJ12 | | | 5.67 | 7.24 | 6.05 | 2.29 | 1.86 | 4.76 | 8.52 |

Table B2. Calibration Phase wave periods in prototype sec.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Wave Direction S80W (35 deg west of centerline) | | | | | | | | | |
| BPJ09 | 6 | No | 6.0 | 6.0 | 5.9 | 6.0 | 6.0 | 6.2 | 5.6 |
| BPJ10 | | | 9.9 | 9.9 | 9.9 | 9.9 | 9.6 | 9.9 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | 13.6 | 13.6 | 13.6 | 13.6 | 14.8 |
| BPJ12 | | | 17.7 | 16.9 | 18.7 | 16.9 | 18.7 | 17.7 | 18.7 |
| Wave Direction S25W (20 deg south of centerline) | | | | | | | | | |
| BPJ09 | 7 | No | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 6.0 | 6.2 |
| BPJ10 | | | 10.1 | 10.1 | 9.9 | 9.9 | 9.9 | 10.1 | 10.1 |
| BPJ11 | | | 13.6 | 14.2 | 14.2 | 14.2 | 13.6 | 14.2 | 14.2 |
| BPJ12 | | | 18.7 | 17.7 | 16.9 | | 18.7 | 17.7 | 17.7 |
| BPJ09 | 8 | 225 | 5.9 | 5.9 | 5.9 | 6.1 | 6.0 | 6.1 | 6.4 |
| BPJ10 | | | 10.1 | 10.1 | 9.9 | 9.9 | 9.9 | 10.1 | 10.1 |
| BPJ11 | | | 13.6 | 14.2 | 14.2 | 13.6 | 13.6 | 13.6 | 14.2 |
| BPJ12 | | | 18.7 | 17.7 | 16.9 | | 18.7 | 17.7 | 17.7 |
| BPJ09 | 9 | 450 | 6.0 | 5.9 | 5.9 | 6.2 | 6.0 | 6.1 | 6.4 |
| BPJ10 | | | 10.1 | 10.1 | 9.9 | 10.1 | 9.9 | 10.1 | 10.1 |
| BPJ11 | | | 13.6 | 14.2 | 14.2 | 14.2 | | 14.2 | 14.2 |
| BPJ12 | | | 18.7 | 17.7 | 16.9 | | 18.7 | 17.7 | 17.7 |
| Notes:<br>1. Blank = Bad or missing data | | | | | | | | | |

# Appendix C: Ship Speed Trial Data

Table C1. Speed trial calibration speeds.

| Inbound | | Outbound | |
|---|---|---|---|
| Tachometer | Speed (kts) | Tachometer | Speed (kts) |
| *President Lincoln* | | | |
| 3 | 3.29 | | |
| 3 | 3.14 | | |
| 4 | 5.84 | 4 | 5.56 |
| 4 | 5.39 | 4 | 4.81 |
| 5 | 7.73 | 5 | 6.78 |
| 5 | 7.68 | 5 | 8.23 |
| 6 | 9.25 | 6 | 8.30 |
| 6 | 9.56 | 6 | 8.35 |
| 7 | 10.67 | 7 | 9.53 |
| 7 | 9.90 | 7 | 9.65 |
| 8 | 11.80 | 8 | 10.61 |
| 8 | 11.58 | 8 | 10.34 |
| *Bunga Saga Empat* | | | |
| 2.2 | 4.72 | 2.2 | 3.83 |
| 2.3 | 5.03 | 2.2 | 4.73 |
| 2.9 | 6.30 | 2.8 | 5.32 |
| 2.8 | 6.37 | 2.9 | 5.93 |
| 3.4 | 7.45 | 3.4 | 6.76 |
| 3.4 | 7.33 | 3.4 | 6.68 |
| 3.9 | 8.21 | 3.9 | 7.43 |
| 3.9 | 8.25 | 3.9 | 7.61 |
| 4.5 | 9.35 | 4.5 | 8.33 |
| 4.5 | 9.34 | 4.4 | 8.53 |
| 4.9 | 10.22 | 4.9 | 9.37 |
| 4.9 | 10.06 | 4.9 | 9.27 |
| 5.5 | 11.17 | 5.5 | 10.04 |
| 5.5 | 11.45 | 5.5 | 9.97 |
| 5.9 | 11.63 | 6 | 10.48 |
| 5.9 | 11.91 | 5.9 | 10.53 |

| Inbound | | Outbound | |
|---|---|---|---|
| Tachometer | Speed (kts) | Tachometer | Speed (kts) |
| *Kukahi* Barge | | | |
| 4.6 | 2.68 | 4.5 | 2.50 |
| 4.6 | 2.58 | 4.6 | 2.55 |
| 5.5 | 2.97 | 5.5 | 2.85 |
| 5.5 | 3.28 | 5.6 | 2.94 |
| 5.5 | 3.37 | 5.6 | 3.02 |
| 6.5 | 3.96 | 6.5 | 3.55 |
| 6.5 | 4.04 | 6.5 | 3.46 |

# Appendix D: Production Phase Wave Data

Table D1. Production Phase wave heights in prototype feet for S80W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 12 | No | 6.2 | 5.9 | Out | Out | Out | 7.5 | 4.2 |
| BPJ10 | | | 6.8 | 6.1 | Out | Out | Out | 7.8 | 4.1 |
| BPJ11 | | | 5.3 | 5.8 | Out | Out | Out | 6.6 | 3.0 |
| BPJ12 | | | 4.7 | 6.5 | Out | Out | Out | 7.4 | 3.3 |
| BPJ09 | 11 | | 7.1 | 6.6 | Out | Out | Out | 7.6 | 4.4 |
| BPJ10 | | | | | Out | Out | Out | | |
| BPJ11 | | | 5.9 | 6.1 | Out | Out | Out | 6.7 | 3.5 |
| BPJ12 | | | 4.8 | 6.5 | Out | Out | Out | 7.5 | 3.4 |
| BPJ09 | 13 | | 7.9 | 7.0 | Out | Out | Out | 8.0 | 5.7 |
| BPJ10 | | | 8.2 | 6.5 | Out | Out | Out | 8.8 | 5.6 |
| BPJ11 | | | 6.0 | 6.3 | Out | Out | Out | 7.1 | 4.0 |
| BPJ12 | | | 5.1 | 6.9 | Out | Out | Out | 7.7 | 4.2 |
| BPJ09 | 17 | 225 | 8.6 | 6.4 | Out | Out | Out | 8.2 | 5.7 |
| BPJ10 | | | 8.5 | 7.1 | Out | Out | Out | 8.7 | 5.7 |
| BPJ11 | | | 6.3 | 6.6 | Out | Out | Out | 7.4 | 4.3 |
| BPJ12 | | | 5.3 | 6.7 | Out | Out | Out | 8.0 | 4.2 |
| BPJ09 | 19 | | 7.5 | 6.7 | Out | Out | Out | 8.1 | 5.3 |
| BPJ10 | | | 7.9 | 6.9 | Out | Out | Out | 8.6 | 5.7 |
| BPJ11 | | | 6.2 | 6.5 | Out | Out | Out | 7.4 | 4.2 |
| BPJ12 | | | 5.7 | 7.1 | Out | Out | Out | 7.9 | 4.4 |
| BPJ09 | 14 | 450 | 7.4 | 6.5 | Out | Out | Out | 7.6 | 4.7 |
| BPJ10 | | | 7.1 | 6.4 | Out | Out | Out | 7.9 | 4.8 |
| BPJ11 | | | 5.3 | 6.3 | Out | Out | Out | 6.6 | 3.1 |
| BPJ12 | | | 4.5 | 6.5 | Out | Out | Out | 7.4 | 3.5 |
| BPJ09 | 15 | | 7.6 | 6.8 | Out | Out | Out | 7.3 | 4.6 |
| BPJ10 | | | 6.6 | 6.4 | Out | Out | Out | 8.0 | 4.0 |
| BPJ11 | | | 5.4 | 6.0 | Out | Out | Out | 6.7 | 3.2 |
| BPJ12 | | | 5.0 | 6.8 | Out | Out | Out | 7.6 | 3.5 |
| BPJ09 | 16 | | 7.5 | 7.3 | Out | Out | Out | 8.2 | 5.6 |
| BPJ10 | | | 7.8 | 6.7 | Out | Out | Out | 8.6 | 6.0 |
| BPJ11 | | | 6.4 | 6.6 | Out | Out | Out | 7.5 | 3.8 |
| BPJ12 | | | 5.2 | 7.0 | Out | Out | Out | 7.8 | 4.4 |

Notes:
1. Blank = Bad or missing data
2. Out = Gage removed for tests with vessels in channel

Table D2. Production Phase wave heights in prototype feet for S25W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 21 | No | 8.4 | 7.8 | Out | Out | Out | 5.1 | 7.5 |
| BPJ10 | | | 7.8 | 7.8 | Out | Out | Out | 5.1 | 7.3 |
| BPJ11 | | | 5.9 | 6.0 | Out | Out | Out | 4.8 | 8.1 |
| BPJ12 | | | 5.7 | 7.2 | Out | Out | Out | 4.5 | 8.3 |
| BPJ09 | 27 | | 8.4 | 7.5 | Out | Out | Out | 5.8 | 7.5 |
| BPJ10 | | | 6.9 | 6.2 | Out | Out | Out | 3.7 | 6.1 |
| BPJ11 | | | 6.2 | 5.9 | Out | Out | Out | 4.8 | 8.3 |
| BPJ12 | | | 5.6 | 7.0 | Out | Out | Out | 4.6 | 8.4 |
| BPJ09 | 23 | 450 | 8.3 | 7.5 | Out | Out | Out | 5.3 | 7.2 |
| BPJ10 | | | 8.1 | 7.9 | Out | Out | Out | 5.6 | 8.0 |
| BPJ11 | | | 6.3 | 6.2 | Out | Out | Out | 5.0 | 7.9 |
| BPJ12 | | | 5.6 | 7.3 | Out | Out | Out | 4.9 | 8.4 |
| BPJ09 | 29 | | 7.9 | 7.5 | Out | Out | Out | 6.7 | 7.1 |
| BPJ10 | | | 8.0 | 7.6 | Out | Out | Out | 6.0 | 7.2 |
| BPJ11 | | | 6.2 | 6.2 | Out | Out | Out | 4.8 | 8.3 |
| BPJ12 | | | 5.6 | 7.4 | Out | Out | Out | 4.2 | 8.2 |

Notes:
1. Blank = Bad or missing data
2. Out = Gage removed for tests with vessels in channel

Table D3. Production Phase wave periods in prototype sec for S80W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 12 | No | 6.0 | 5.9 | Out | Out | Out | 6.3 | 6.0 |
| BPJ10 | | | 9.9 | 9.9 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 14.8 |
| BPJ12 | | | 17.7 | 16.9 | Out | Out | Out | 17.7 | 18.7 |
| BPJ09 | 11 | | 6.1 | 5.9 | Out | Out | Out | 6.1 | 5.9 |
| BPJ10 | | | | | Out | Out | Out | | |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 13.6 |
| BPJ12 | | | 17.7 | 17.7 | Out | Out | Out | 17.7 | 16.9 |
| BPJ09 | 13 | | 6.1 | 5.9 | Out | Out | Out | 6.1 | 6.0 |
| BPJ10 | | | 9.9 | 10.1 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 14.8 |
| BPJ12 | | | 17.7 | 17.7 | Out | Out | Out | 17.7 | 18.7 |
| BPJ09 | 17 | 225 | 6.0 | 6.0 | Out | Out | Out | 6.2 | 5.9 |
| BPJ10 | | | 9.9 | 9.9 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 14.8 |
| BPJ12 | | | 17.7 | 17.7 | Out | Out | Out | 16.9 | 16.9 |
| BPJ09 | 19 | | 6.1 | 6.1 | Out | Out | Out | 6.1 | 6.0 |
| BPJ10 | | | 9.9 | 10.1 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 14.8 |
| BPJ12 | | | 17.7 | 17.7 | Out | Out | Out | 16.9 | 16.9 |
| BPJ09 | 14 | 450 | 5.9 | 6.0 | Out | Out | Out | 6.0 | 5.5 |
| BPJ10 | | | 9.9 | 9.9 | Out | Out | Out | 10.1 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 13.6 |
| BPJ12 | | | 17.7 | 16.9 | Out | Out | Out | 17.7 | 16.9 |
| BPJ09 | 15 | | 5.9 | 5.9 | Out | Out | Out | 6.3 | 5.7 |
| BPJ10 | | | 9.9 | 9.9 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 13.6 |
| BPJ12 | | | 17.7 | 16.9 | Out | Out | Out | 17.7 | 18.7 |
| BPJ09 | 16 | | 6.1 | 6.0 | Out | Out | Out | 6.2 | 5.9 |
| BPJ10 | | | 9.9 | 10.1 | Out | Out | Out | 10.1 | 10.1 |
| BPJ11 | | | 14.2 | 14.2 | Out | Out | Out | 13.6 | 13.6 |
| BPJ12 | | | 17.7 | 17.7 | Out | Out | Out | 18.7 | 18.7 |

Notes:
1. Blank = Bad or missing data
2. Out = Gage removed for tests with vessels in channel

Table D4. Production Phase wave periods in prototype sec for S25W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 21 | No | 5.9 | 6.0 | Out | Out | Out | 6.0 | 6.3 |
| BPJ10 | | | 10.1 | 10.1 | Out | Out | Out | 10.1 | 10.1 |
| BPJ11 | | | 13.3 | 13.8 | Out | Out | Out | 13.3 | 14.4 |
| BPJ12 | | | 18.7 | 17.7 | Out | Out | Out | 17.7 | 17.7 |
| BPJ09 | 27 | | 6.2 | 6.0 | Out | Out | Out | 5.9 | 5.6 |
| BPJ10 | | | 10.1 | 9.9 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 13.6 | 14.2 | Out | Out | Out | 14.2 | 14.2 |
| BPJ12 | | | 18.7 | 17.7 | Out | Out | Out | 17.7 | 17.7 |
| BPJ09 | 23 | 450 | 5.9 | 6.0 | Out | Out | Out | 5.9 | 5.7 |
| BPJ10 | | | 10.1 | 10.1 | Out | Out | Out | 10.1 | 10.1 |
| BPJ11 | | | 13.6 | 14.2 | Out | Out | Out | 13.6 | 14.2 |
| BPJ12 | | | 18.7 | 17.7 | Out | Out | Out | 17.7 | 17.7 |
| BPJ09 | 29 | | 5.6 | 5.9 | Out | Out | Out | 6.0 | 5.6 |
| BPJ10 | | | 10.1 | 9.9 | Out | Out | Out | 9.9 | 10.1 |
| BPJ11 | | | 13.6 | 14.2 | Out | Out | Out | 13.6 | 14.2 |
| BPJ12 | | | 18.7 | 17.7 | Out | Out | Out | 17.7 | 17.7 |

Notes:
1. Blank = Bad or missing data
2. Out = Gage removed for tests with vessels in channel

# Appendix E: Optimization Phase Wave Data

Table E1. Optimization Phase wave heights in prototype feet for S25W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 35 | No | 8.4 | 7.4 | 3.4 | 3.1 | 2.5 | 5.3 | 0.8 |
| BPJ10 | | | 8.1 | 7.8 | 3.2 | 2.9 | 2.4 | 5.7 | 1.2 |
| BPJ11 | | | 6.3 | 6.3 | 2.7 | 2.4 | 2.0 | 4.6 | 1.0 |
| BPJ12 | | | 5.6 | 7.3 | 2.0 | 1.8 | 1.6 | 4.3 | 1.0 |
| BPJ09 | 34 | 375 | 8.2 | 7.1 | 3.3 | 3.0 | 2.4 | 5.3 | 0.8 |
| BPJ10 | | | 8.2 | 7.9 | 3.2 | 2.9 | 2.4 | 5.7 | 1.1 |
| BPJ11 | | | 6.3 | 6.1 | 2.4 | 2.2 | 1.8 | 4.9 | 1.0 |
| BPJ12 | | | 5.7 | 7.2 | 1.8 | 1.8 | 1.6 | 4.6 | 1.0 |
| BPJ09 | 44 | | 8.3 | 7.4 | 3.2 | 2.9 | 2.2 | 6.1 | 0.8 |
| BPJ10 | | | 8.2 | 7.8 | 3.3 | 3.0 | 2.4 | 5.7 | 1.2 |
| BPJ11 | | | 6.3 | 6.1 | 2.5 | 2.2 | 1.8 | 5.1 | 1.0 |
| BPJ12 | | | 5.7 | 7.2 | 1.9 | 1.8 | 1.6 | 4.6 | 1.0 |
| BPJ09 | 33 | 400 | 8.2 | 7.5 | 3.3 | 2.9 | 2.3 | 5.8 | 0.8 |
| BPJ10 | | | 8.1 | 7.8 | 3.3 | 2.8 | 2.3 | 6.1 | 1.1 |
| BPJ11 | | | 6.3 | 6.3 | 2.5 | 2.2 | 1.8 | 5.0 | 1.0 |
| BPJ12 | | | 5.7 | 7.3 | 1.9 | 1.8 | 1.6 | 4.7 | 1.0 |
| BPJ09 | 43 | | 8.1 | 7.2 | 3.4 | 3.0 | 2.3 | 5.3 | 0.8 |
| BPJ10 | | | 8.2 | 7.9 | 3.1 | 2.8 | 2.3 | 5.7 | 1.1 |
| BPJ11 | | | 6.3 | 6.2 | 2.3 | 2.1 | 1.8 | 4.9 | 1.0 |
| BPJ12 | | | 5.6 | 7.2 | 1.8 | 1.6 | 1.5 | 4.5 | 1.0 |
| BPJ09 | 32 | 425 | 8.3 | 7.3 | 3.4 | 2.9 | 2.3 | 5.4 | 0.8 |
| BPJ10 | | | 8.1 | 7.8 | 3.2 | 2.7 | 2.3 | 5.8 | 1.1 |
| BPJ11 | | | 5.8 | 5.7 | 2.3 | 1.8 | 1.5 | 4.5 | 0.9 |
| BPJ12 | | | 5.3 | 6.9 | 1.6 | 1.5 | 1.3 | 4.4 | 0.9 |
| BPJ09 | 42 | | 8.2 | 7.5 | 3.7 | 3.0 | 2.2 | 6.0 | 0.8 |
| BPJ10 | | | 8.2 | 7.9 | 4.1 | 2.9 | 2.4 | 5.8 | 1.2 |
| BPJ11 | | | 6.3 | 6.3 | 2.4 | 2.2 | 1.8 | 4.9 | 1.0 |
| BPJ12 | | | 5.7 | 7.3 | 1.9 | 1.8 | 1.6 | 4.5 | 1.0 |

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 31 | 450 | 8.7 | 8.1 | 3.6 | 2.9 | 2.3 | 5.8 | 0.8 |
| BPJ10 | | | 8.4 | 7.9 | 3.2 | 2.7 | 2.3 | 6.3 | 1.2 |
| BPJ11 | | | 6.5 | 6.3 | 2.9 | 2.1 | 1.8 | 5.3 | 1.0 |
| BPJ12 | | | 5.9 | 7.4 | 2.4 | 1.7 | 1.6 | 4.8 | 1.1 |
| BPJ09 | 41 | | 8.3 | 7.2 | 3.4 | 3.0 | 2.3 | 5.3 | 0.8 |
| BPJ10 | | | 8.2 | 7.9 | 3.3 | 2.9 | 2.4 | 6.0 | 1.2 |
| BPJ11 | | | 6.3 | 6.1 | 4.1 | 2.2 | 1.9 | 5.1 | 1.0 |
| BPJ12 | | | 5.7 | 7.3 | 2.4 | 1.7 | 1.5 | 4.4 | 1.0 |
| Notes:<br>1. Blank = Bad or missing data | | | | | | | | | |

Table E2. Optimization Phase normalized wave heights for S25W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 35 | No | 1.14 | 1.00 | 0.45 | 0.42 | 0.34 | 0.71 | 0.11 |
| BPJ10 | | | 1.04 | 1.00 | 0.41 | 0.37 | 0.31 | 0.73 | 0.15 |
| BPJ11 | | | 1.00 | 1.00 | 0.43 | 0.38 | 0.31 | 0.74 | 0.16 |
| BPJ12 | | | 0.78 | 1.00 | 0.27 | 0.24 | 0.22 | 0.60 | 0.14 |
| BPJ09 | 34, 44 | 375 | 1.12 | 0.98 | 0.44 | 0.40 | 0.31 | 0.77 | 0.11 |
| BPJ10 | | | 1.05 | 1.00 | 0.42 | 0.37 | 0.31 | 0.73 | 0.15 |
| BPJ11 | | | 1.00 | 0.98 | 0.39 | 0.36 | 0.29 | 0.80 | 0.15 |
| BPJ12 | | | 0.78 | 1.00 | 0.26 | 0.24 | 0.22 | 0.63 | 0.14 |
| BPJ09 | 33, 43 | 400 | 1.10 | 0.99 | 0.45 | 0.40 | 0.31 | 0.75 | 0.10 |
| BPJ10 | | | 1.04 | 1.01 | 0.41 | 0.36 | 0.30 | 0.75 | 0.15 |
| BPJ11 | | | 1.00 | 0.99 | 0.38 | 0.35 | 0.28 | 0.80 | 0.15 |
| BPJ12 | | | 0.78 | 1.00 | 0.25 | 0.23 | 0.21 | 0.63 | 0.14 |
| BPJ09 | 32, 42 | 425 | 1.11 | 1.00 | 0.48 | 0.40 | 0.30 | 0.77 | 0.11 |
| BPJ10 | | | 1.04 | 1.01 | 0.47 | 0.36 | 0.30 | 0.74 | 0.15 |
| BPJ11 | | | 0.96 | 0.96 | 0.37 | 0.32 | 0.27 | 0.75 | 0.15 |
| BPJ12 | | | 0.76 | 0.98 | 0.24 | 0.23 | 0.20 | 0.61 | 0.13 |
| BPJ09 | 31, 41 | 450 | 1.15 | 1.03 | 0.47 | 0.39 | 0.31 | 0.75 | 0.11 |
| BPJ10 | | | 1.06 | 1.02 | 0.41 | 0.36 | 0.30 | 0.79 | 0.15 |
| BPJ11 | | | 1.02 | 0.99 | 0.56 | 0.35 | 0.29 | 0.83 | 0.16 |
| BPJ12 | | | 0.79 | 1.01 | 0.33 | 0.24 | 0.21 | 0.64 | 0.15 |
| Notes:<br>1. Gages normalized by gage 2 $H_{m0}$: BPJ09: $H_{m0}$ = 7.41 ft, BPJ10: $H_{m0}$ = 7.80 ft, BPJ11: $H_{m0}$ = 6.27 ft, BPJ12: $H_{m0}$ = 7.25 ft | | | | | | | | | |

Table E3. Optimization Phase wave periods in prototype sec for S25W wave direction.

| Signal | Run | Jetty | Gage Number | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| BPJ09 | 35 | No | 6.0 | 6.1 | 6.0 | 5.9 | 5.9 | 6.0 | |
| BPJ10 | | | 10.1 | 9.9 | 9.9 | 4.4 | 9.9 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | | 4.3 | 4.3 | 14.2 | |
| BPJ12 | | | 18.7 | 17.7 | 18.7 | | 18.7 | 17.7 | |
| BPJ09 | 34 | 375 | 6.2 | 6.1 | 6.0 | 6.2 | 5.9 | 6.0 | |
| BPJ10 | | | 10.1 | 9.9 | 4.4 | 4.5 | 4.5 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | 14.2 | | | 14.2 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |
| BPJ09 | 44 | | 6.0 | 6.1 | 6.1 | 6.2 | 5.9 | 6.2 | |
| BPJ10 | | | 10.1 | 10.1 | 4.5 | 4.7 | 4.5 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | 14.2 | | | 14.2 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |
| BPJ09 | 33 | 400 | 6.0 | 6.1 | 6.0 | 6.2 | 5.9 | 6.0 | |
| BPJ10 | | | 10.1 | 9.9 | 4.6 | 8.2 | 9.9 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | | | | 14.2 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |
| BPJ09 | 43 | | 6.0 | 6.1 | 6.0 | 6.2 | 5.9 | 6.0 | |
| BPJ10 | | | 10.1 | 9.9 | 4.4 | 4.5 | 8.2 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | 14.2 | | | 14.2 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |
| BPJ09 | 32 | 425 | 5.9 | 6.1 | 6.0 | 6.0 | 6.0 | 6.0 | |
| BPJ10 | | | 10.1 | 9.9 | 4.4 | 8.2 | 4.5 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | | | | 13.6 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |
| BPJ09 | 42 | | 6.0 | 6.0 | | 6.3 | 5.9 | 6.2 | |
| BPJ10 | | | 10.1 | 9.9 | | 4.5 | 4.5 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | 14.2 | | | 13.6 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |
| BPJ09 | 31 | 450 | 6.0 | 6.1 | | 6.0 | 5.9 | 6.0 | |
| BPJ10 | | | 10.1 | 9.9 | 4.6 | 4.7 | 4.7 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | | | | 13.6 | |
| BPJ12 | | | 18.7 | 17.7 | | | 18.7 | 17.7 | 18.7 |
| BPJ09 | 41 | | 6.0 | 6.0 | 6.0 | 6.0 | 5.9 | 6.0 | |
| BPJ10 | | | 10.1 | 10.1 | 4.5 | | 4.6 | 10.1 | |
| BPJ11 | | | 13.6 | 13.6 | | | | 13.6 | |
| BPJ12 | | | 18.7 | 17.7 | | | | 17.7 | |

Notes:
1. Blank = Bad or missing data

# Appendix F: Calibration Phase Current Patterns

(a) Mvc-364f, BPJ09306.

(b) Mvc-366f, BPJ09306.

Photo F1. Two views of wave and current patterns for Base Case with no-jetty for T=6 sec wave case, S80W wave direction, Calibration Phase.

(a) Mvc-369f, BPJ10306.

(b) Mvc-371f, BPJ10306.

Photo F2. Two views of wave and current patterns for Base Case with no-jetty for $T$=10 sec wave case, S80W wave direction, Calibration Phase.

(a) Mvc-377f, BPJ11306.

(b) Mvc-379f, BPJ11306.

Photo F3. Two views of wave and current patterns for Base Case with no-jetty for *T*=14 sec wave case, S80W wave direction, Calibration Phase.

(a) Mvc-389f, BPJ12306.

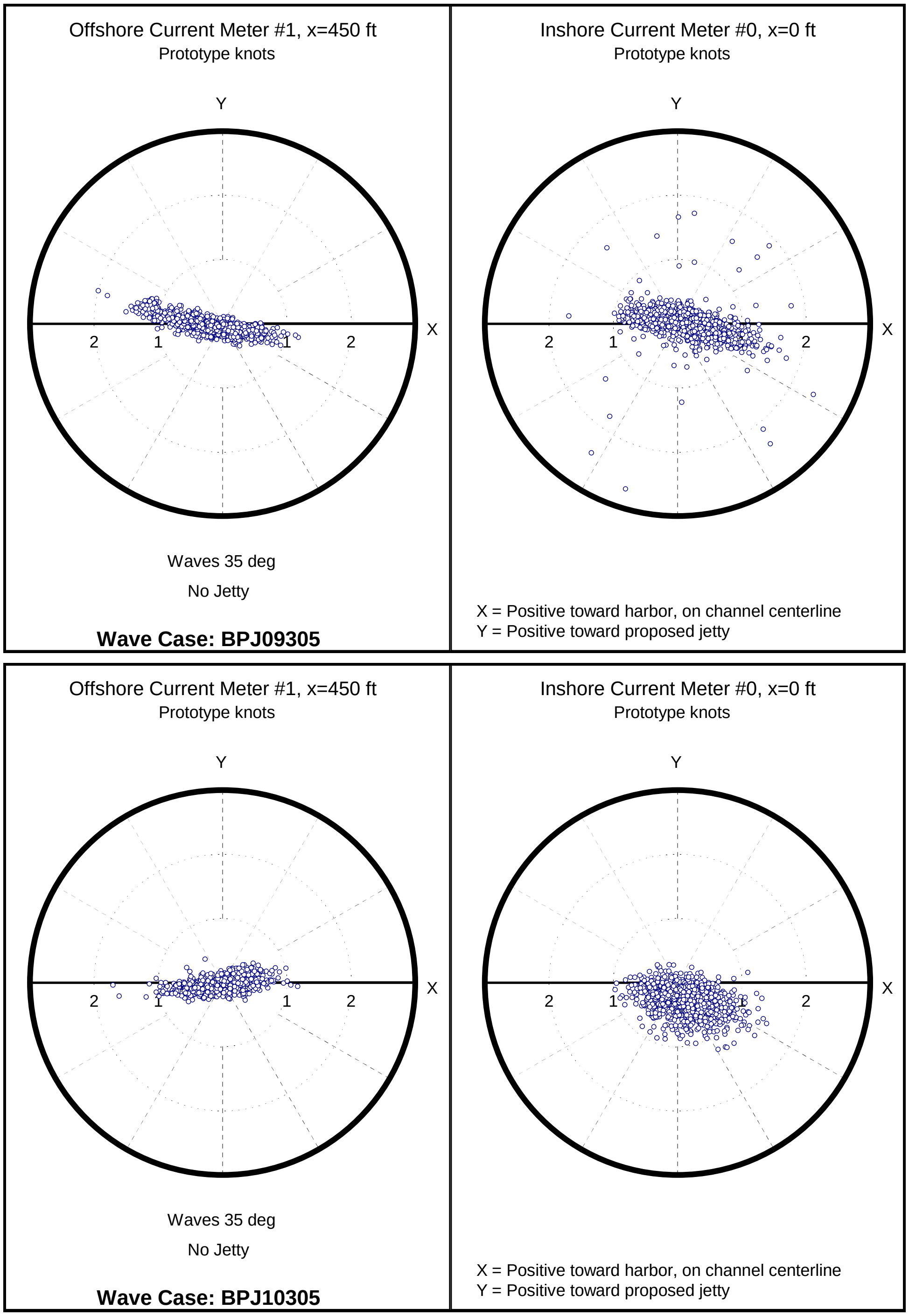
(b) Mvc-391f, BPJ12306.

Photo F4. Two views of wave and current patterns for Base Case with no-jetty for *T*=18 sec wave case, S80W wave direction, Calibration Phase.

# Appendix G: Current Vector Polar Plots

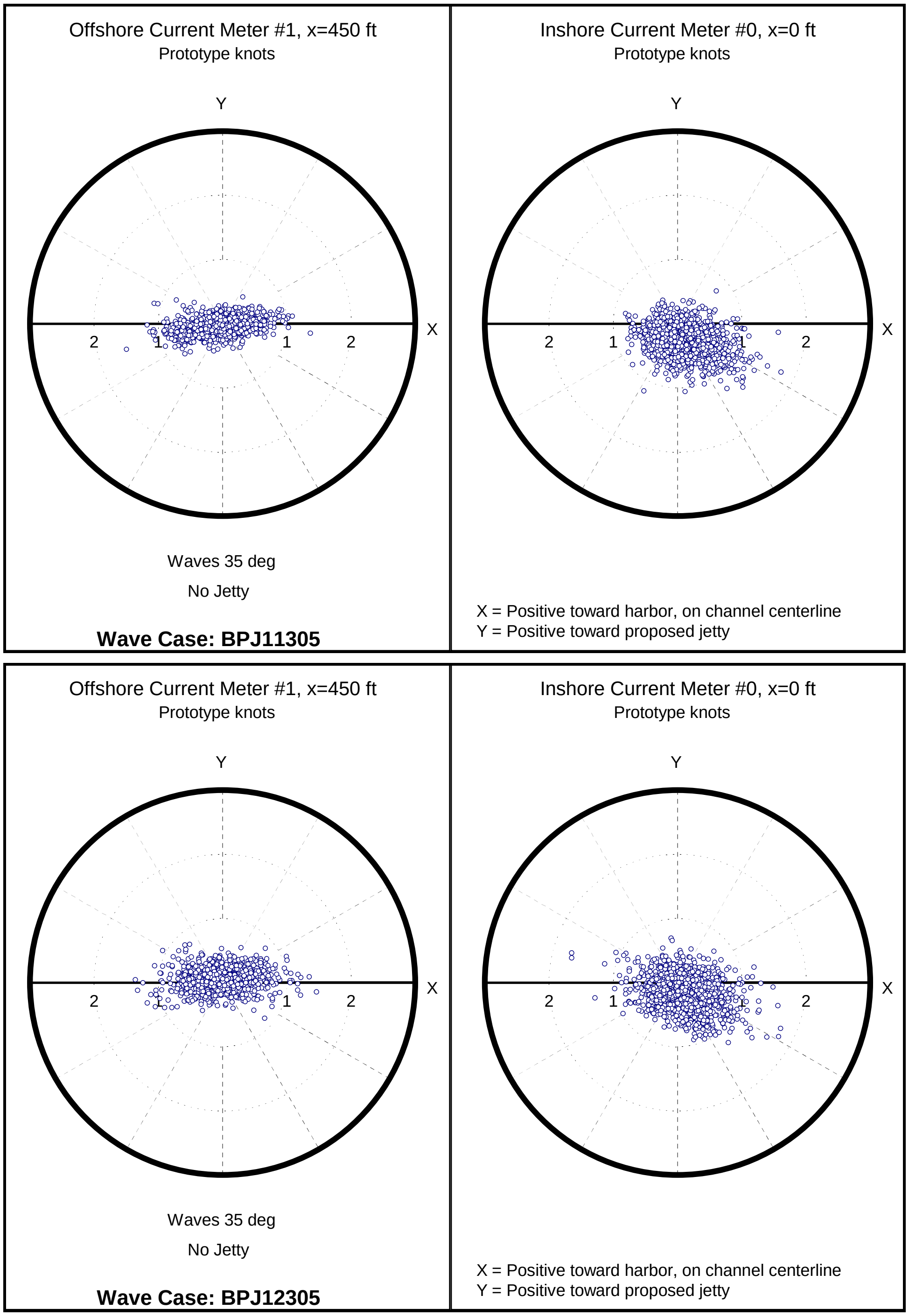
Notes:

1. Wave direction annotation on polar plots for “Waves 35 deg” is the same as S80W in the main body of the report.
2. Wave direction annotation on polar plots for “Waves 20 deg” is the same as S25W in the main body of the report.



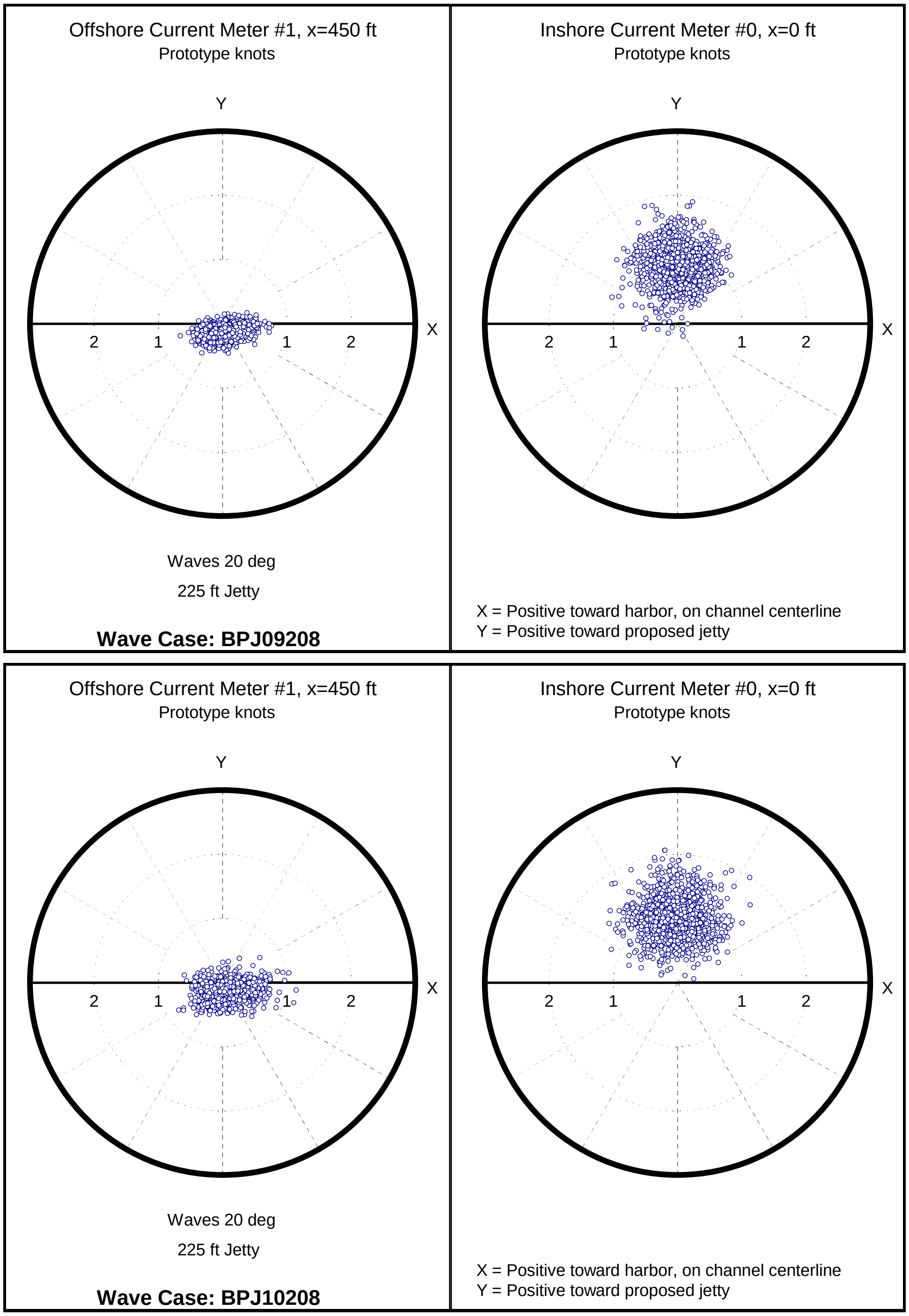

(a) Top row: $T_p$ = 6 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 10 sec and $x$ = 0 and 450 ft current meter locations.

Figure G1. Current meter vector polar plots for no-jetty configuration, S80W wave direction, Run 05, Calibration Phase (Continued).



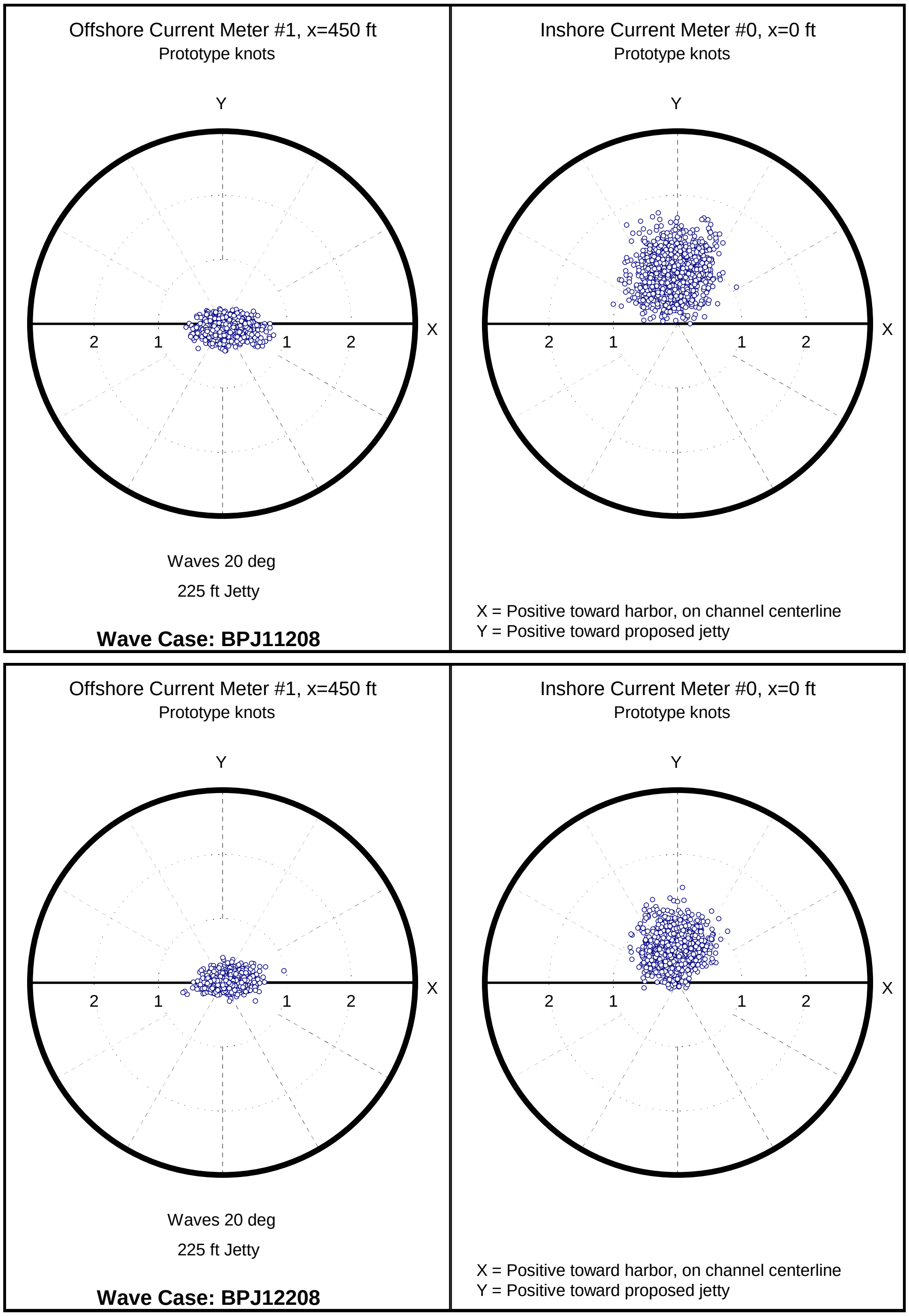

(b) Top row: $T_p$ = 14 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 18 sec and $x$ = 0 and 450 ft current meter locations.

Figure G1. (Concluded).



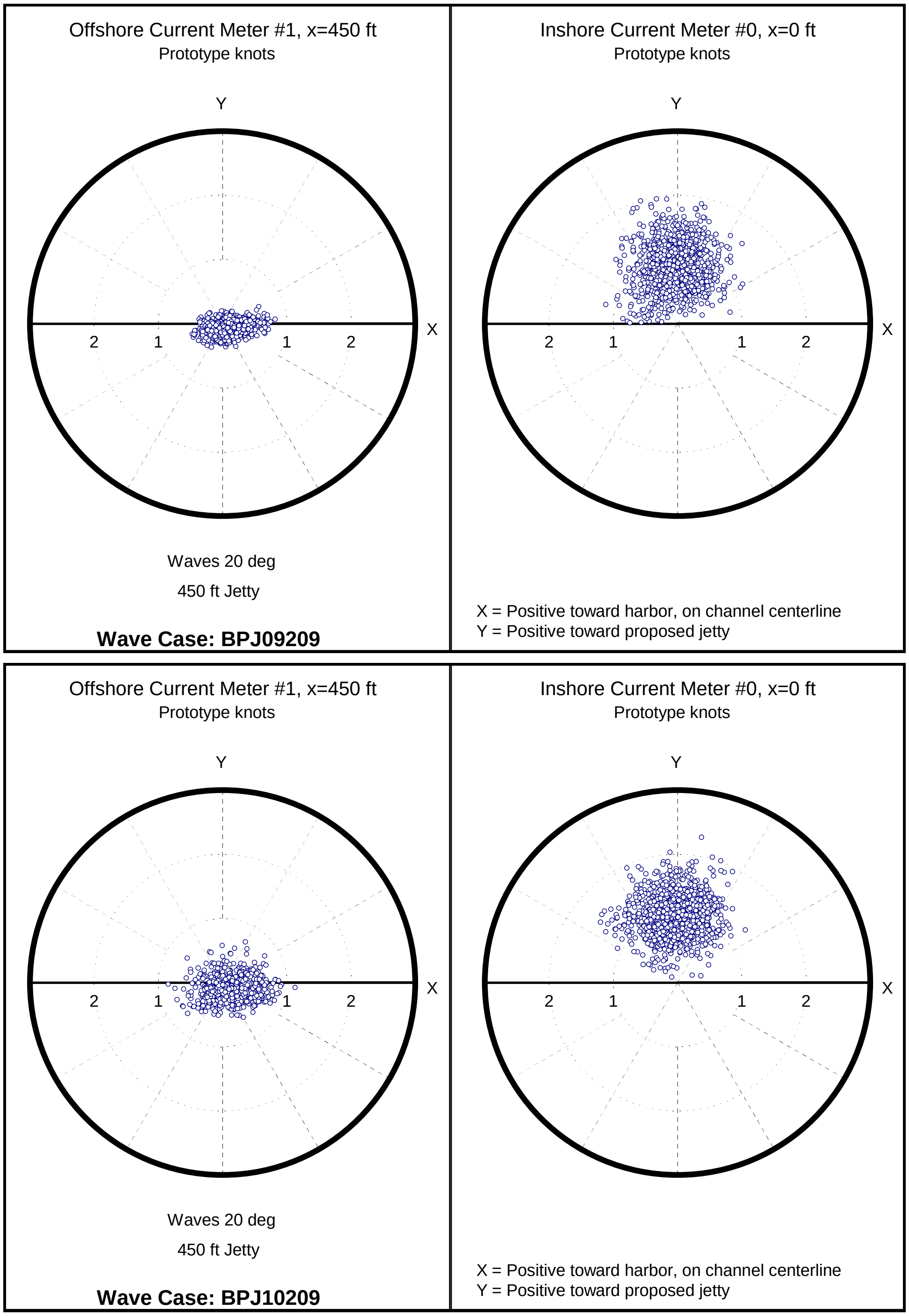

(a) Top row: $T_p$ = 6 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 10 sec and $x$ = 0 and 450 ft current meter locations.

Figure G2. Current meter vector polar plots for 225-ft jetty configuration, S25W wave direction, Calibration Phase (Continued).



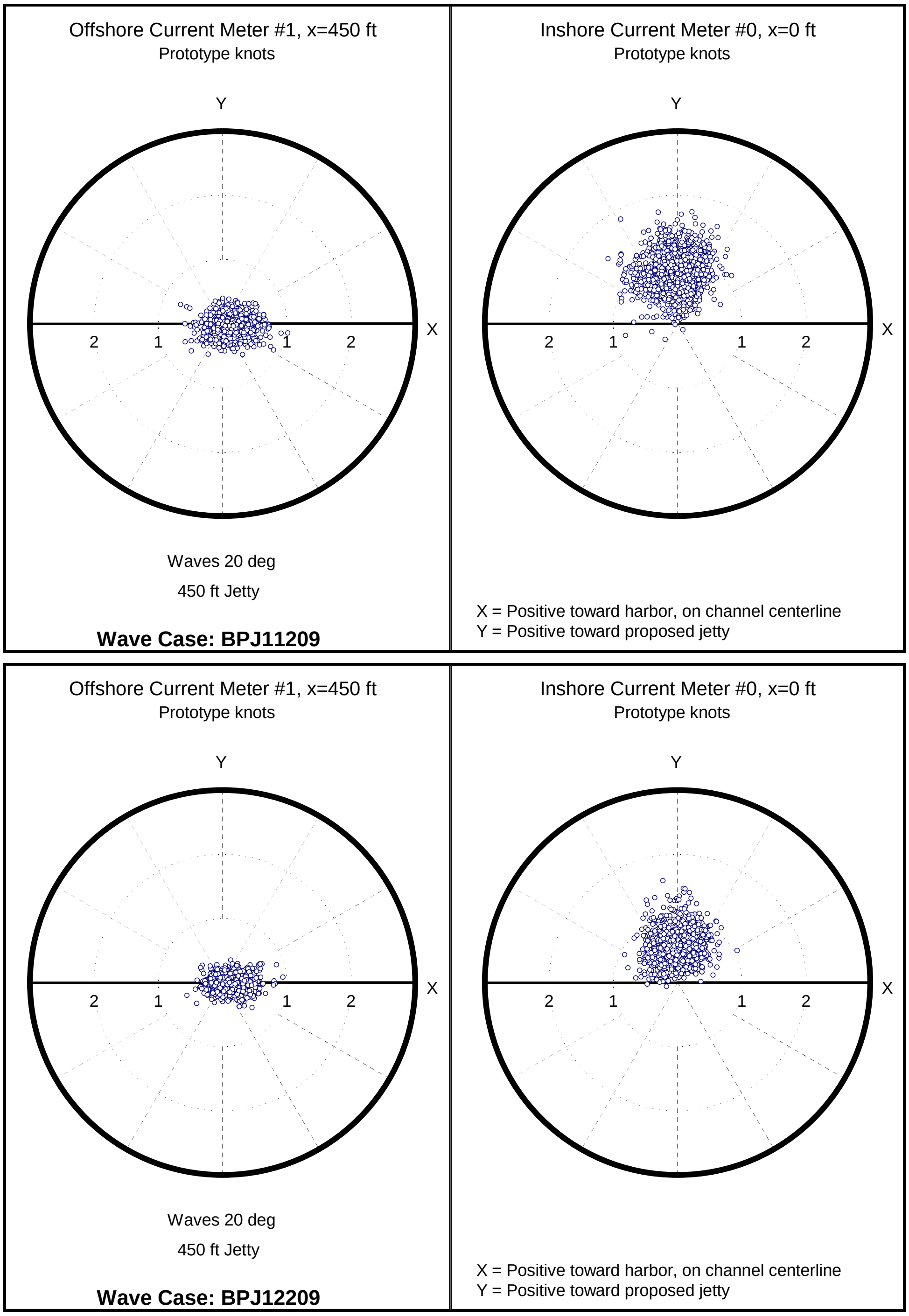

(b) Top row: $T_p$ = 14 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 18 sec and $x$ = 0 and 450 ft current meter locations.

Figure G2. (Concluded).



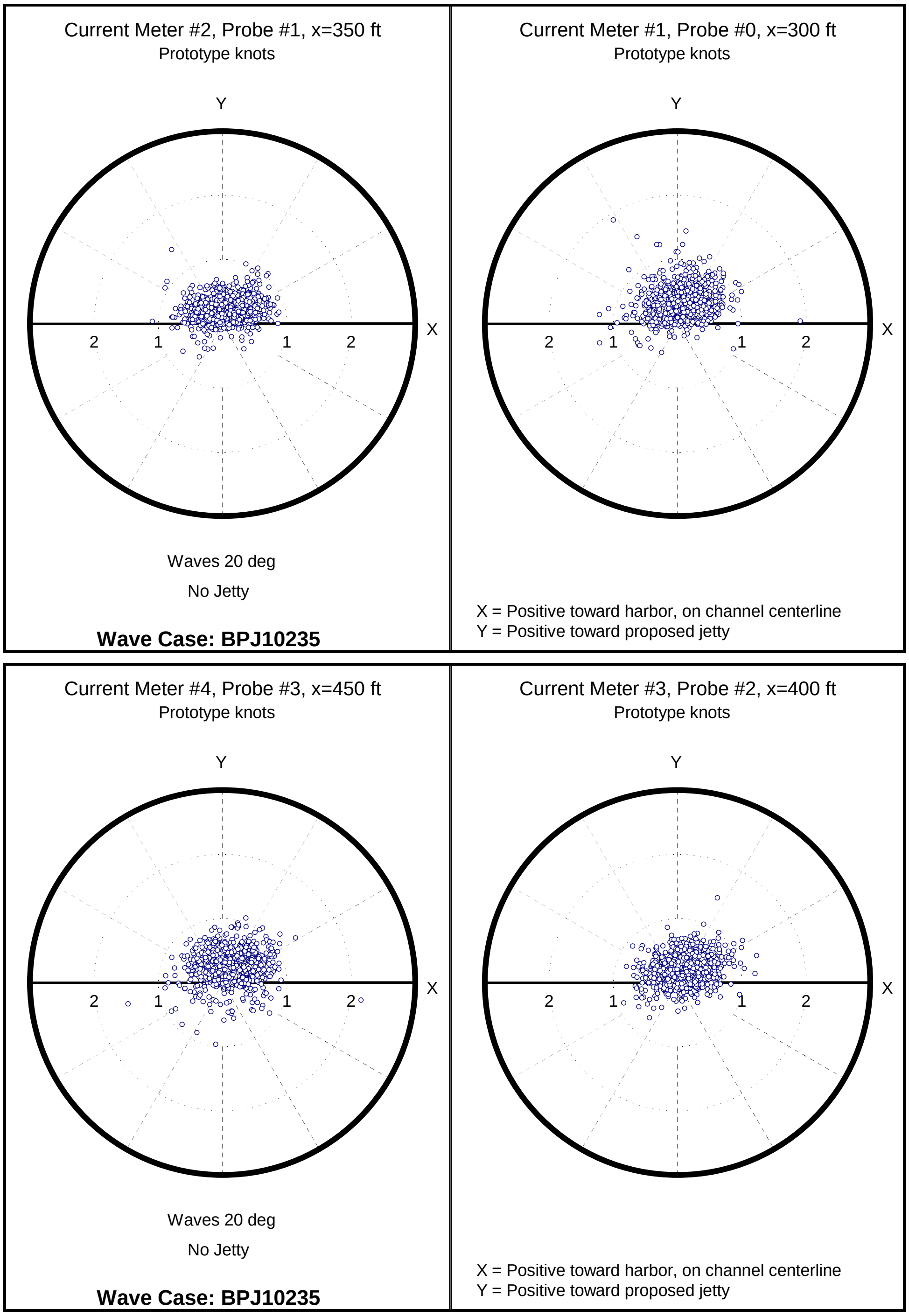

(a) Top row: $T_p$ = 6 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 10 sec and $x$ = 0 and 450 ft current meter locations.

Figure G3. Current meter vector polar plots for 450-ft jetty configuration, S25W wave direction, Calibration Phase (Continued).



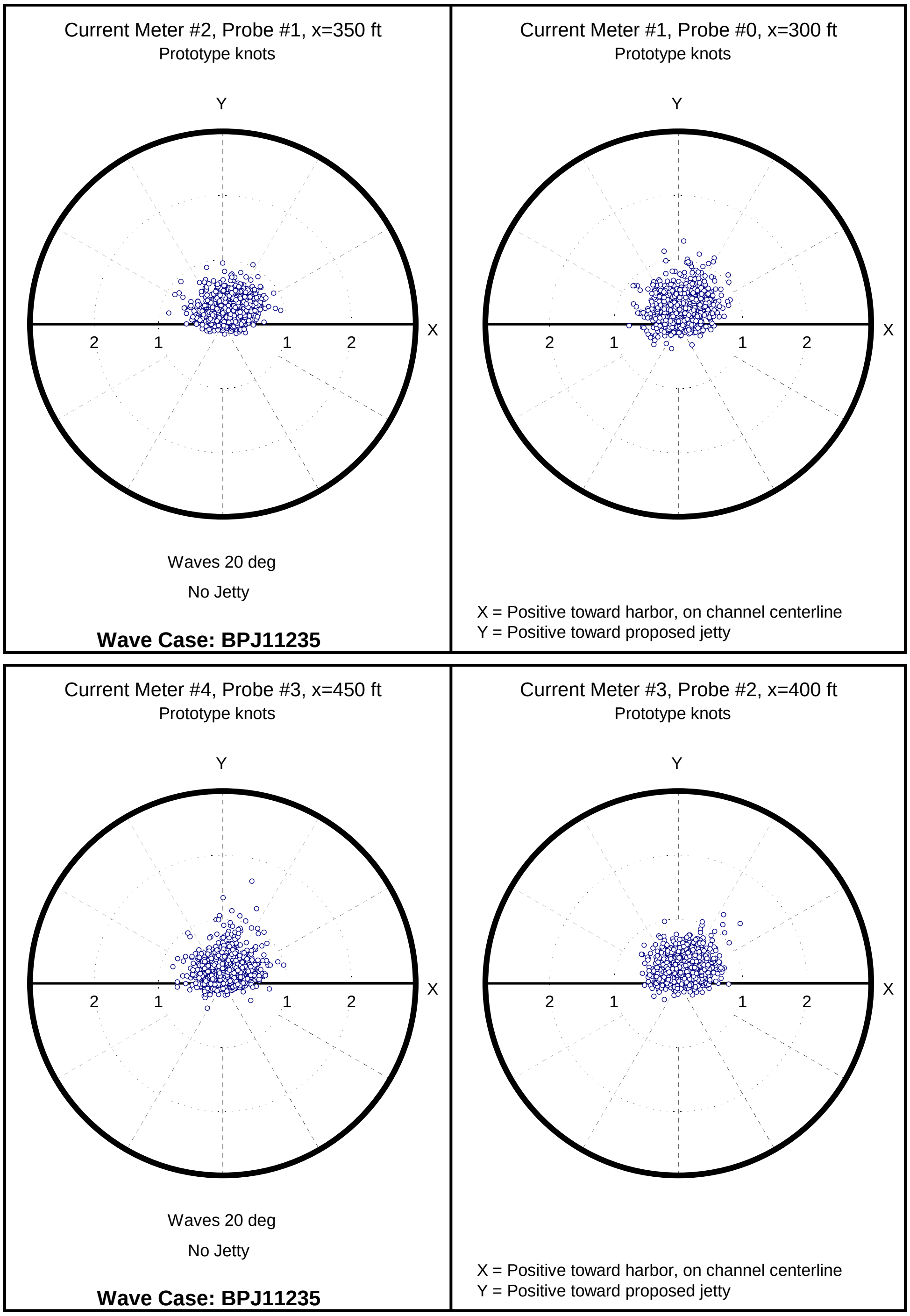

(b) Top row: $T_p$ = 14 sec and $x$ = 0 and 450 ft current meter locations.
Bottom row: $T_p$ = 18 sec and $x$ = 0 and 450 ft current meter locations.

Figure G3. (Concluded).



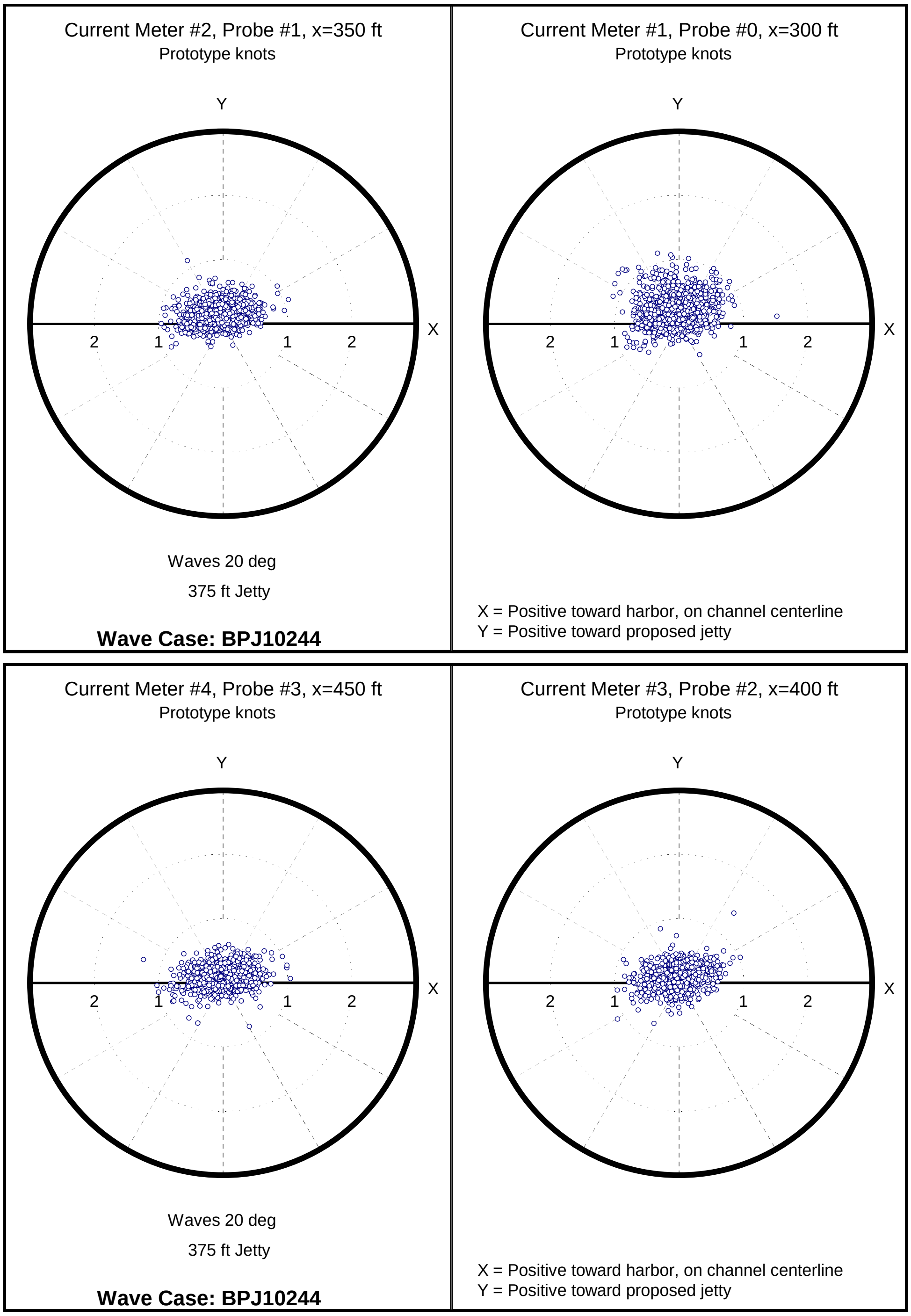

(a) $T_p$ = 10 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G4. Current vector polar plots for no-jetty configuration, S25W wave direction, Optimization Phase (Continued).



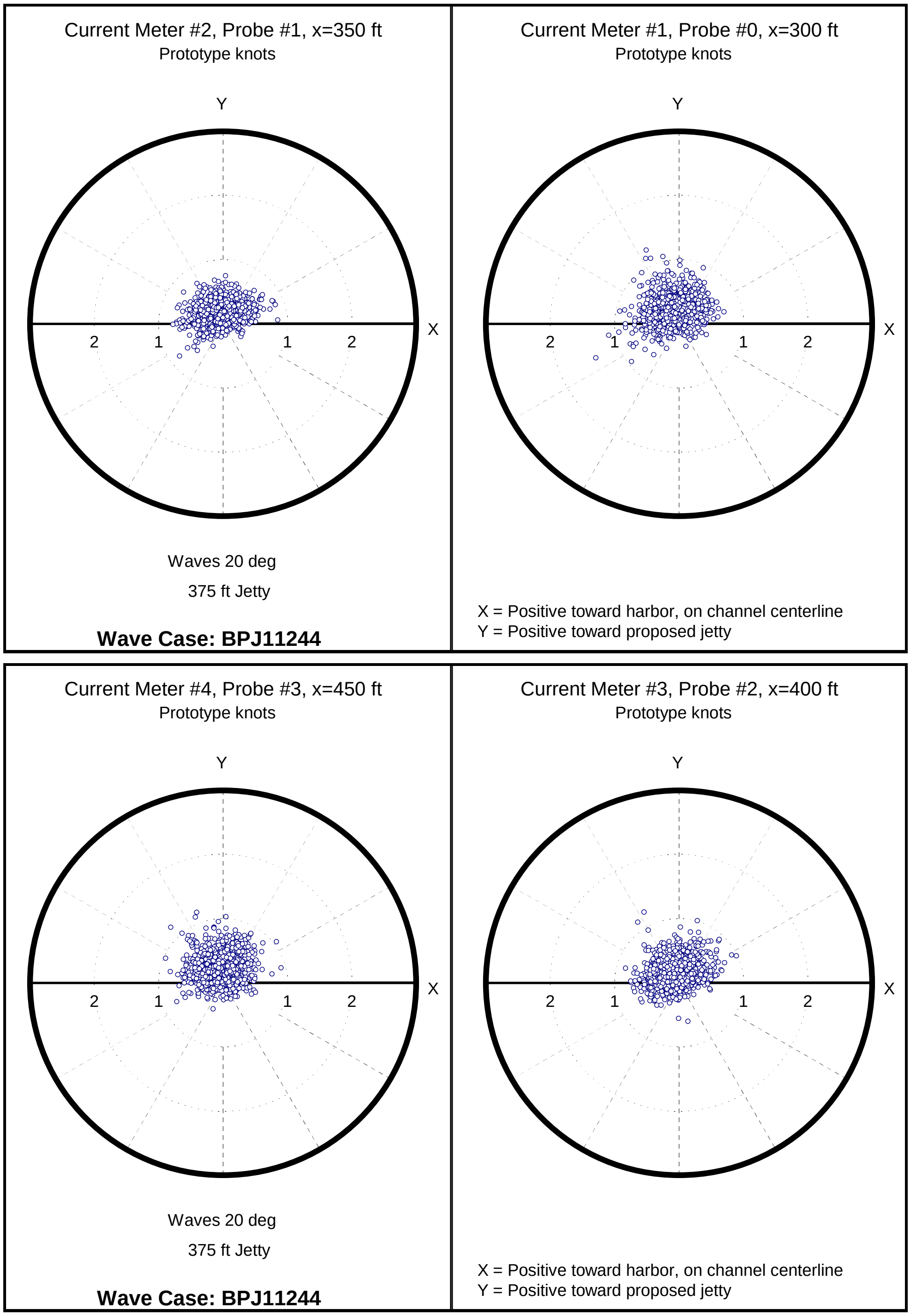

(b) $T_p$ = 14 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G4. (Concluded).



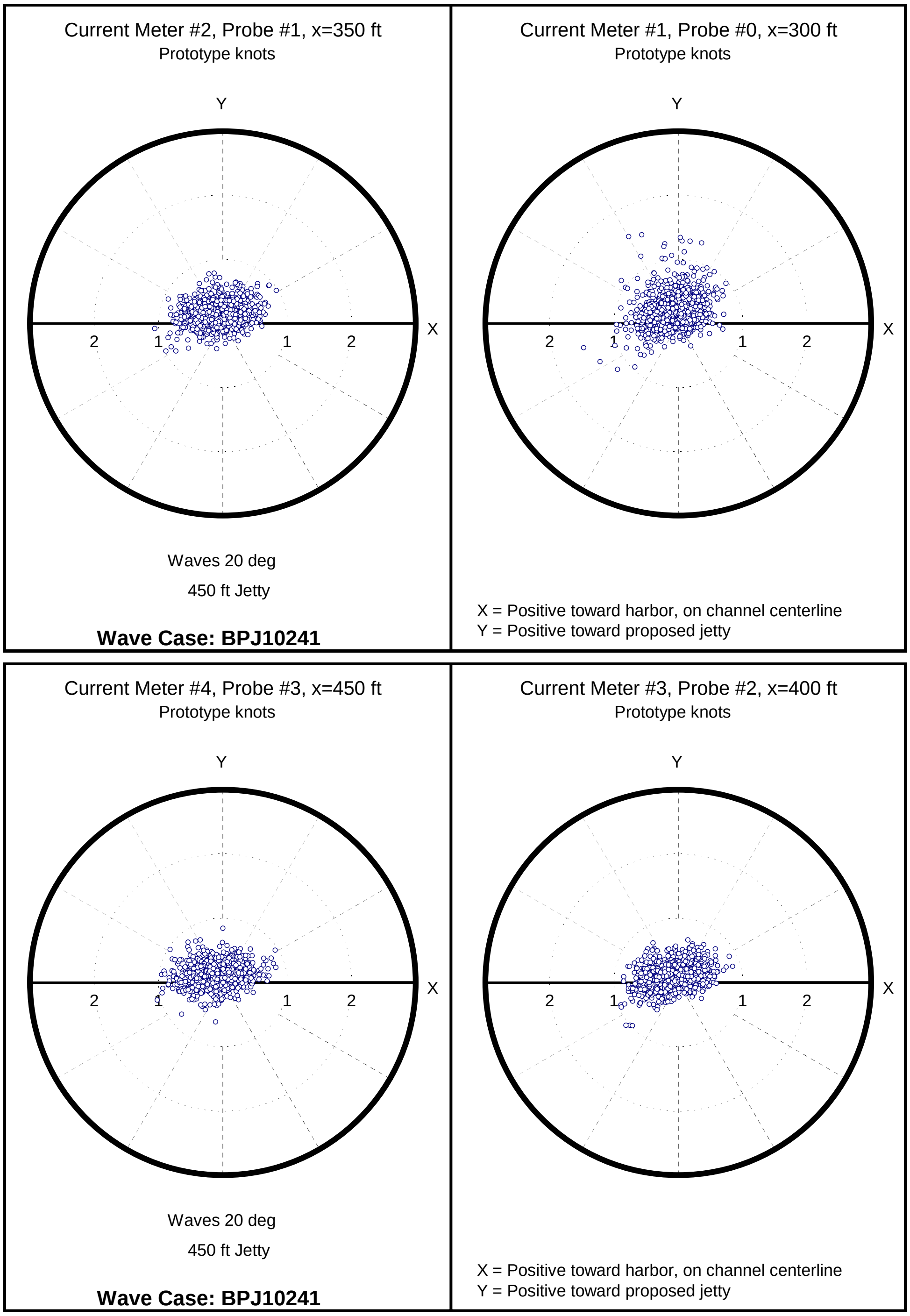

(a) $T_p$ = 10 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G5. Current vector polar plots for 375-ft-long jetty configuration, S25W wave direction, Optimization Phase (Continued).



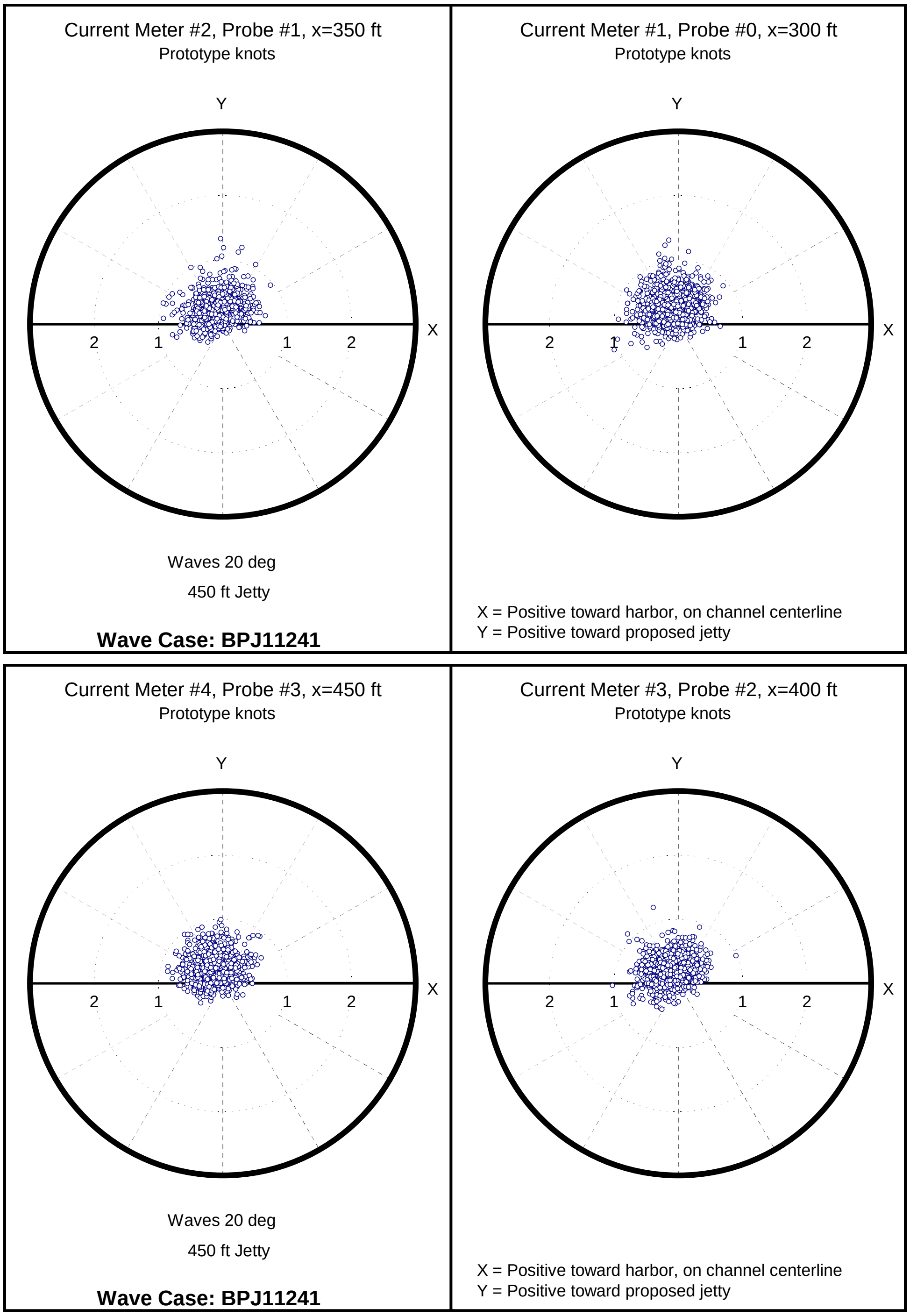

(b) $T_p$ = 14 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G5. (Concluded).



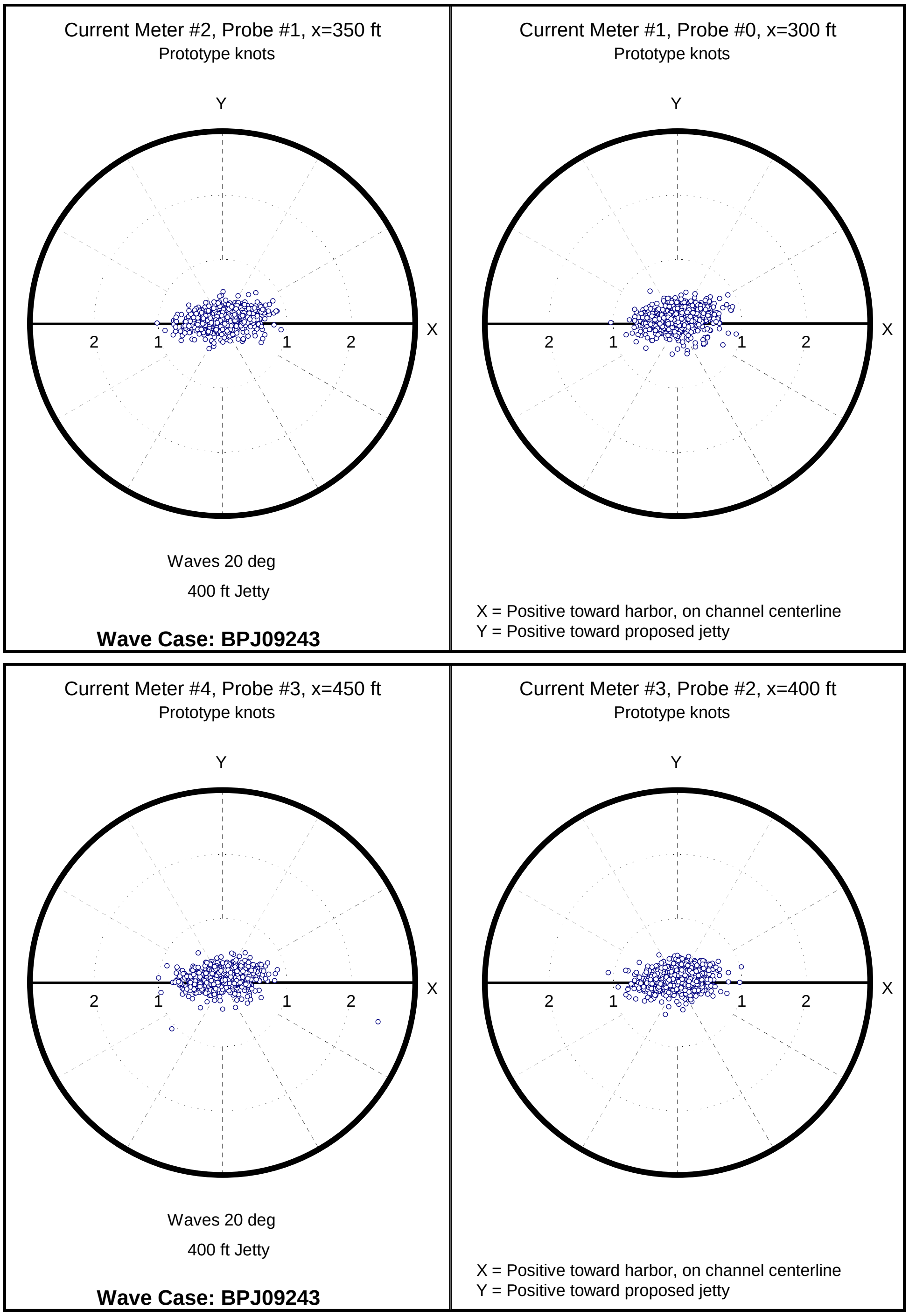

(a) $T_p$ = 10 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G6. Current vector polar plots for 450-ft-long jetty configuration, S25W wave direction, Optimization Phase (Continued).



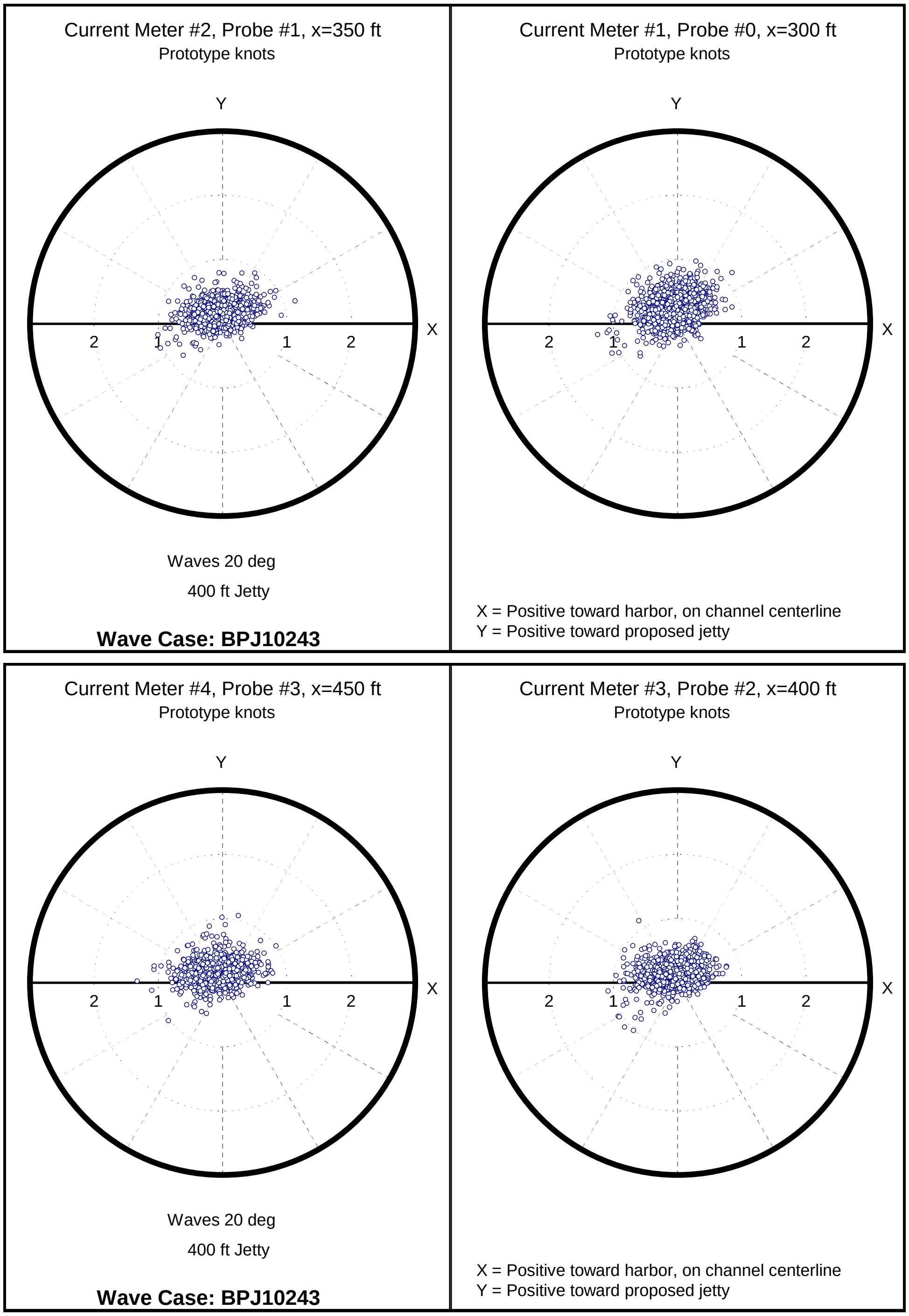

(b) $T_p$ = 14 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G6. (Concluded).



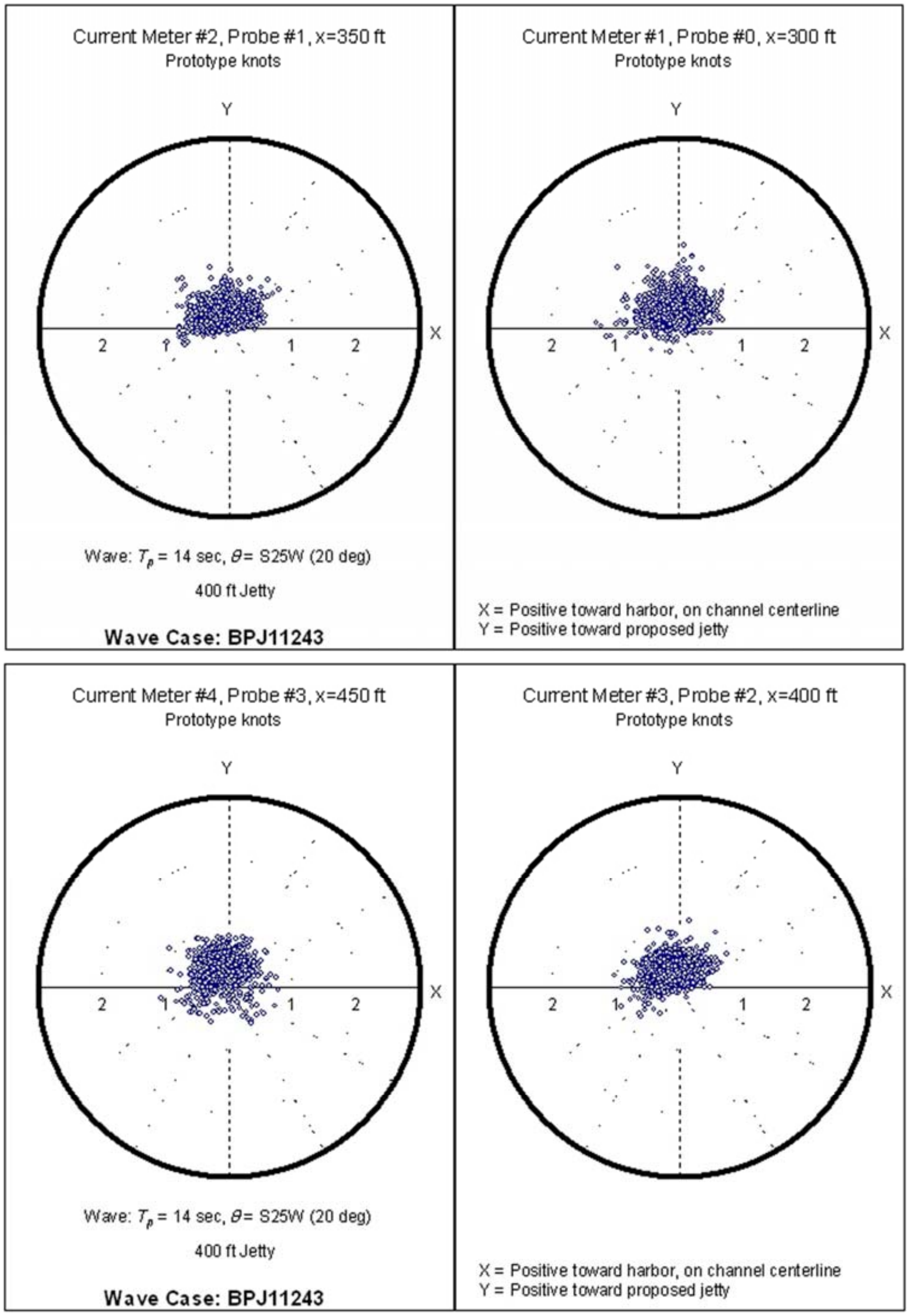

(a) $T$ = 6 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G7. Current vector polar plot for 400-ft-long jetty configuration, S25W wave direction, Optimization Phase (Continued).



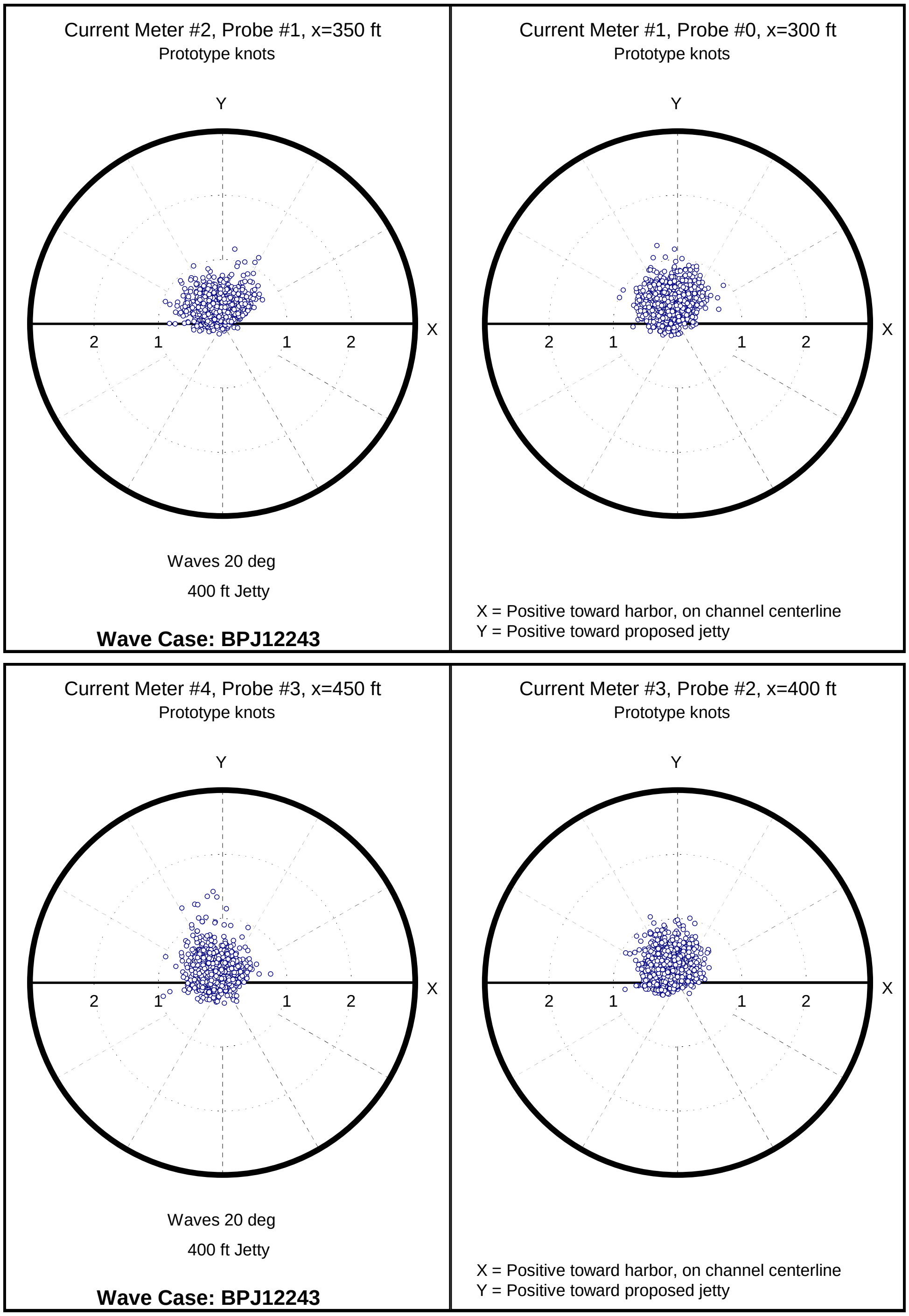

(b) $T$ = 10 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G7. (Continued).



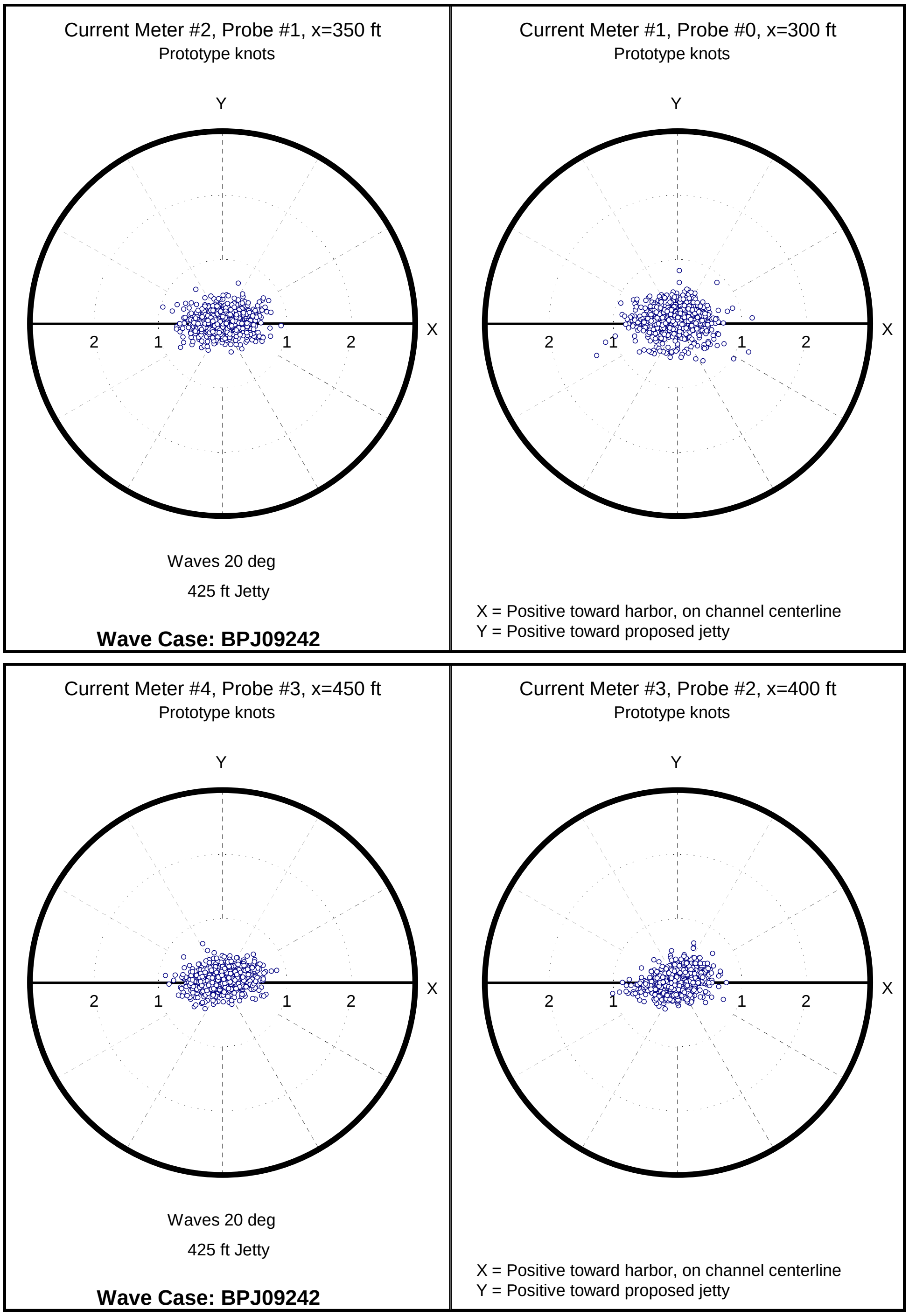

(c) $T$ = 14 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G7. (Continued).



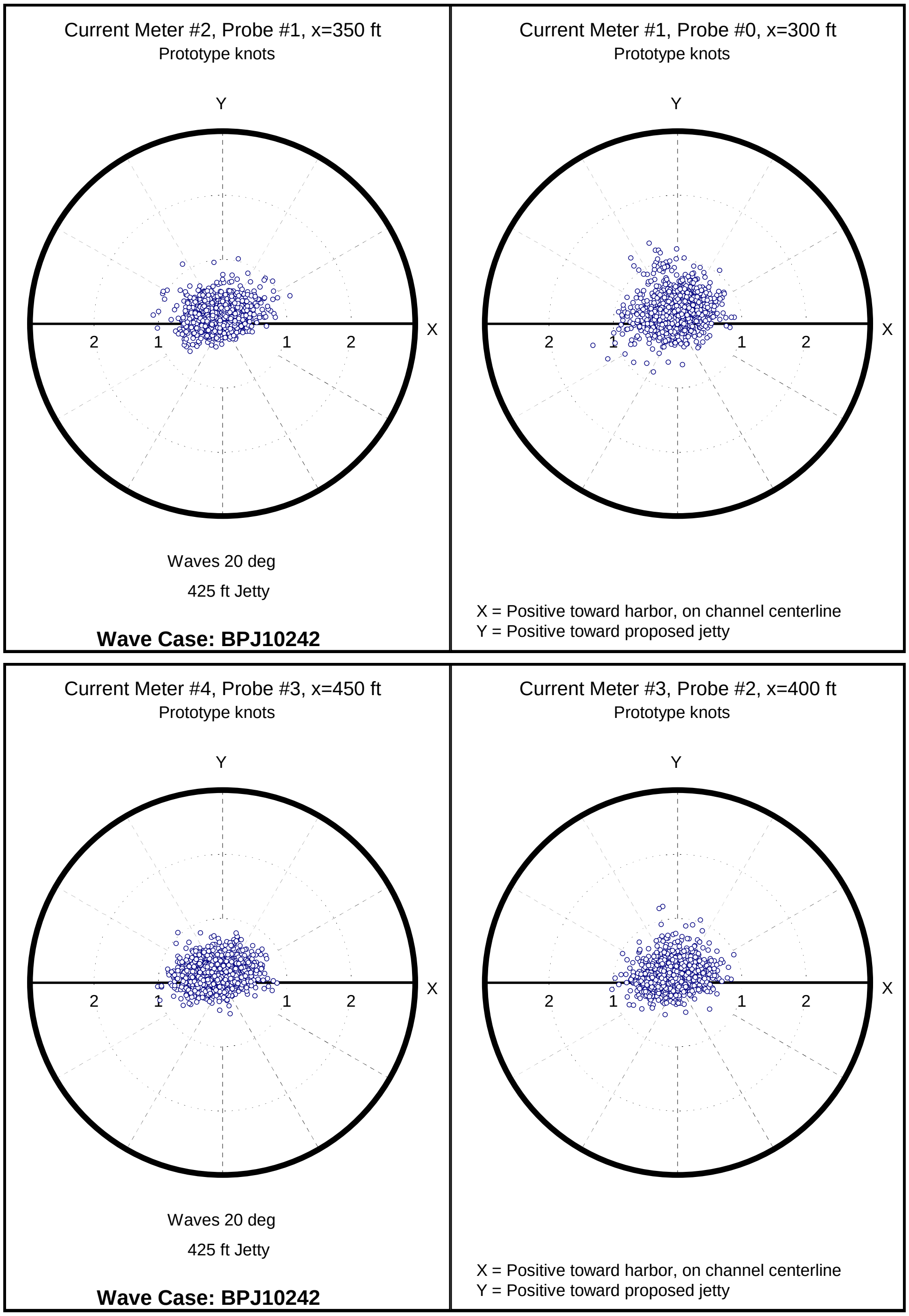

(d) $T$ = 18 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G7. (Concluded).



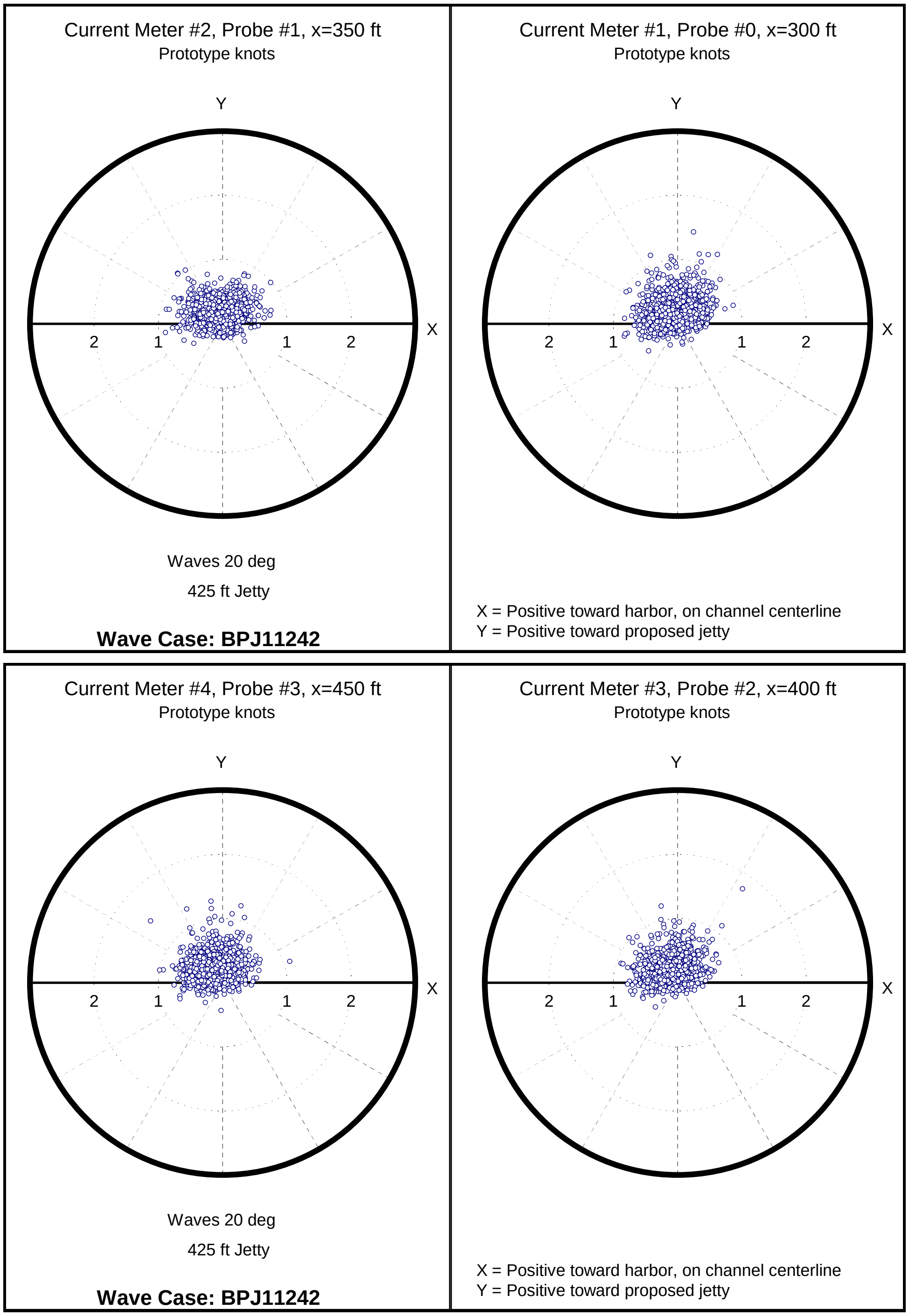

(a) $T$ = 6 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G8. Current vector polar plot for 425-ft-long jetty configuration, S25W wave direction, Optimization Phase (Continued).



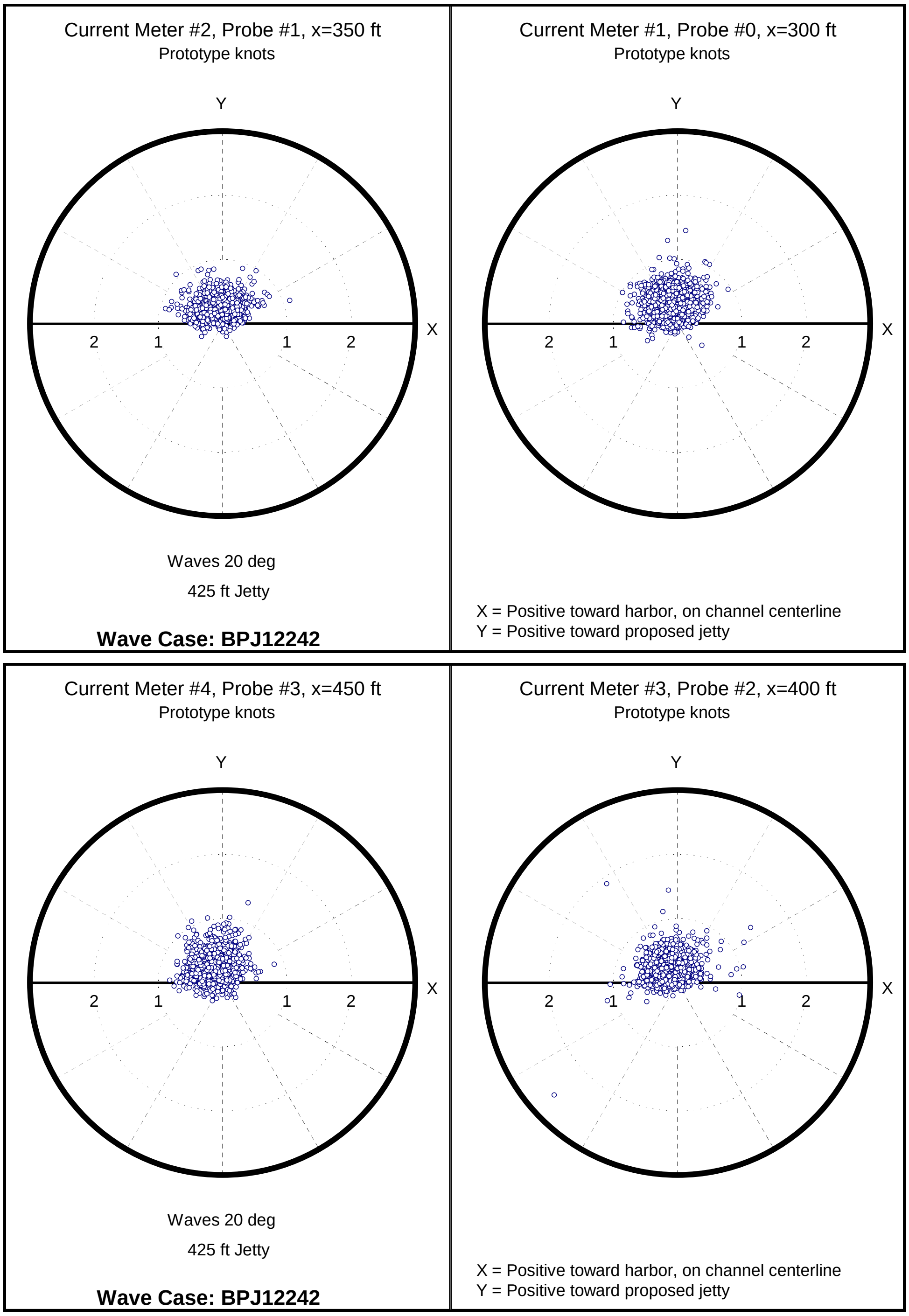

(b) $T$ = 10 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G8. (Continued).




(c) $T$ = 14 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G8. (Continued).




(d) $T$ = 18 sec, $x$ = 300, 350, 400, and 450 ft current meter locations.

Figure G8. (Concluded).

# Appendix H: Current Meter Velocity Data

Table H1. Calibration Phase current U-velocity in knots

| Signal | Run | Jetty | Current Meter Location, ft | |
|---|---|---|---|---|
| | | | 0 | 450 |
| Wave Direction S25W (20 deg from channel centerline) | | | | |
| BPJ09 | 7 | No | 1.37 | 0.92 |
| BPJ10 | | | 1.46 | 1.11 |
| BPJ11 | | | 1.26 | 0.84 |
| BPJ12 | | | 1.00 | 0.70 |
| BPJ09 | 8 | 225 | 1.25 | 0.84 |
| BPJ10 | | | 1.42 | 1.07 |
| BPJ11 | | | 1.20 | 0.90 |
| BPJ12 | | | 0.99 | 0.76 |
| BPJ09 | 8_4gage | | 1.52 | 0.99 |
| BPJ10 | | | 1.50 | 1.06 |
| BPJ11 | | | 1.21 | 0.87 |
| BPJ12 | | | | |
| BPJ09 | 9 | 450 | 1.34 | 0.87 |
| BPJ10 | | | 1.41 | 1.06 |
| BPJ11 | | | 1.23 | 0.88 |
| BPJ12 | | | 1.02 | 0.78 |
| BPJ09 | 9_4gage | | 1.34 | 0.87 |
| BPJ10 | | | 1.51 | 1.02 |
| BPJ11 | | | 1.24 | 0.77 |
| BPJ12 | | | 1.00 | 0.72 |
| Wave Direction S80W (35 deg from channel centerline) | | | | |
| BPJ09 | 5 | No | 2.20 | 1.77 |
| BPJ10 | | | 1.45 | 1.42 |
| BPJ11 | | | 1.51 | 1.45 |
| BPJ12 | | | 1.57 | 1.58 |
| BPJ09 | 6 | | 1.92 | 1.76 |
| BPJ10 | | | 1.79 | 1.87 |
| BPJ11 | | | 1.54 | 1.58 |
| BPJ12 | | | 1.58 | 1.66 |
| Notes:<br>1. Blank = Bad or missing data | | | | |

Table H2. Calibration Phase current V-velocity in knots.

| Signal | Run | Jetty | Current Meter Location, ft | |
|---|---|---|---|---|
| | | | 0 | 450 |
| Wave Direction S25W (20 deg from channel centerline) | | | | |
| BPJ09 | 7 | No | 1.54 | 0.39 |
| BPJ10 | | | 1.34 | 0.56 |
| BPJ11 | | | 1.31 | 0.42 |
| BPJ12 | | | 1.06 | 0.33 |
| BPJ09 | 8 | 225 | 1.24 | 0.39 |
| BPJ10 | | | 1.30 | 0.56 |
| BPJ11 | | | 1.24 | 0.43 |
| BPJ12 | | | 0.98 | 0.41 |
| BPJ09 | 8_4gage | | 1.49 | 0.46 |
| BPJ10 | | | 1.38 | 0.56 |
| BPJ11 | | | 1.17 | 0.47 |
| BPJ12 | | | | |
| BPJ09 | 9 | 450 | 1.40 | 0.40 |
| BPJ10 | | | 1.30 | 0.63 |
| BPJ11 | | | 1.21 | 0.53 |
| BPJ12 | | | 1.03 | 0.45 |
| BPJ09 | 9_4gage | | 1.50 | 0.38 |
| BPJ10 | | | 1.40 | 0.44 |
| BPJ11 | | | 1.29 | 0.32 |
| BPJ12 | | | 0.98 | 0.31 |
| Wave Direction S80W (35 deg from channel centerline) | | | | |
| BPJ09 | 5 | No | | 0.50 |
| BPJ10 | | | 0.84 | 0.36 |
| BPJ11 | | | 0.96 | 0.50 |
| BPJ12 | | | 1.11 | 0.66 |
| BPJ09 | 6 | | 0.61 | 0.49 |
| BPJ10 | | | 0.92 | 0.51 |
| BPJ11 | | | 0.94 | 0.72 |
| BPJ12 | | | 1.15 | 0.84 |

Notes:
1. Blank = Bad or missing data

Table H3. Calibration Phase current magnitude in knots.

| Signal | Run | Jetty | Current Meter Location, ft | |
|---|---|---|---|---|
| | | | 0 | 450 |
| Wave Direction S25W (20 deg from channel centerline) | | | | |
| BPJ09 | 7 | No | 2.06 | 1.00 |
| BPJ10 | | | 1.99 | 1.25 |
| BPJ11 | | | 1.81 | 0.94 |
| BPJ12 | | | 1.46 | 0.77 |
| BPJ09 | 8 | 225 | 1.76 | 0.92 |
| BPJ10 | | | 1.92 | 1.21 |
| BPJ11 | | | 1.72 | 1.00 |
| BPJ12 | | | 1.39 | 0.86 |
| BPJ09 | 8_4gage | | 2.13 | 1.09 |
| BPJ10 | | | 2.04 | 1.20 |
| BPJ11 | | | 1.68 | 0.99 |
| BPJ12 | | | | |
| BPJ09 | 9 | 450 | 1.94 | 0.96 |
| BPJ10 | | | 1.92 | 1.23 |
| BPJ11 | | | 1.72 | 1.03 |
| BPJ12 | | | 1.45 | 0.90 |
| BPJ09 | 9_4gage | | 2.02 | 0.95 |
| BPJ10 | | | 2.06 | 1.11 |
| BPJ11 | | | 1.79 | 0.83 |
| BPJ12 | | | 1.40 | 0.78 |
| Wave Direction S80W (35 deg from channel centerline) | | | | |
| BPJ09 | 5 | No | | 1.84 |
| BPJ10 | | | 1.68 | 1.47 |
| BPJ11 | | | 1.79 | 1.53 |
| BPJ12 | | | 1.92 | 1.71 |
| BPJ09 | 6 | | 2.01 | 1.83 |
| BPJ10 | | | 2.01 | 1.93 |
| BPJ11 | | | 1.81 | 1.74 |
| BPJ12 | | | 1.95 | 1.86 |
| Notes:<br>1. Blank = Bad or missing data | | | | |

Table H4. Calibration Phase average current V-velocity in knots.

| Signal | Run | Jetty | Current Meter Location, ft | |
|---|---|---|---|---|
| | | | 0 | 450 |
| Wave Direction S25W (20 deg from channel centerline) | | | | |
| BPJ09 | 7 | No | 1.54 | 0.39 |
| BPJ10 | | | 1.34 | 0.56 |
| BPJ11 | | | 1.31 | 0.42 |
| BPJ12 | | | 1.06 | 0.33 |
| BPJ09 | 8 & 8_4gage | 225 | 1.36 | 0.42 |
| BPJ10 | | | 1.34 | 0.56 |
| BPJ11 | | | 1.20 | 0.45 |
| BPJ12 | | | 0.98 | 0.41 |
| BPJ09 | 9 & 9_4gage | 450 | 1.45 | 0.39 |
| BPJ10 | | | 1.35 | 0.53 |
| BPJ11 | | | 1.25 | 0.43 |
| BPJ12 | | | 1.01 | 0.38 |
| Wave Direction S80W (35 deg from channel centerline) | | | | |
| BPJ09 | 5 & 6 | No | 0.61 | 1.76 |
| BPJ10 | | | 0.88 | 1.65 |
| BPJ11 | | | 0.95 | 1.52 |
| BPJ12 | | | 1.13 | 1.62 |
| Notes:<br>1. Blank = Bad or missing data | | | | |

Table H5. Calibration Phase average current magnitude in knots.

| Signal | Run | Jetty | Current Meter Location, ft | |
|---|---|---|---|---|
| | | | 0 | 450 |
| Wave Direction S25W (20 deg from channel centerline) | | | | |
| BPJ09 | 7 | No | 2.06 | 1.00 |
| BPJ10 | | | 1.99 | 1.25 |
| BPJ11 | | | 1.81 | 0.94 |
| BPJ12 | | | 1.46 | 0.77 |
| BPJ09 | 8 & 8_4gage | 225 | 1.94 | 1.01 |
| BPJ10 | | | 1.98 | 1.21 |
| BPJ11 | | | 1.70 | 0.99 |
| BPJ12 | | | 0.41 | 1.64 |
| BPJ09 | 9 & 9_4gage | 450 | 1.98 | 0.95 |
| BPJ10 | | | 1.99 | 1.17 |
| BPJ11 | | | 1.76 | 0.93 |
| BPJ12 | | | 1.43 | 0.84 |
| Wave Direction S80W (35 deg from channel centerline) | | | | |
| BPJ09 | 5 & 6 | No | 2.01 | 1.83 |
| BPJ10 | | | 1.84 | 1.70 |
| BPJ11 | | | 1.80 | 1.64 |
| BPJ12 | | | 1.94 | 1.79 |
| Notes:<br>1. Blank = Bad or missing data | | | | |

Table H6. Calibration Phase normalized current magnitudes in knots.

| Signal | Run | Jetty | Current Meter Location, ft | |
|---|---|---|---|---|
| | | | 0 | 450 |
| Wave Direction S25W (20 deg from channel centerline) | | | | |
| BPJ09 | 7 | No | 1.00 | 1.00 |
| BPJ10 | | | 1.00 | 1.00 |
| BPJ11 | | | 1.00 | 1.00 |
| BPJ12 | | | 1.00 | 1.00 |
| BPJ09 | 8 & 8_4gage | 225 | 0.94 | 1.00 |
| BPJ10 | | | 1.00 | 0.97 |
| BPJ11 | | | 0.94 | 1.05 |
| BPJ12 | | | 0.95 | 1.12 |
| BPJ09 | 9 & 9_4gage | 450 | 0.96 | 0.95 |
| BPJ10 | | | 1.00 | 0.94 |
| BPJ11 | | | 0.97 | 0.98 |
| BPJ12 | | | 0.98 | 1.09 |
| Wave Direction S80W (35 deg from channel centerline) | | | | |
| BPJ09 | 5 & 6 | No | 1.00 | 1.00 |
| BPJ10 | | | 1.00 | 1.00 |
| BPJ11 | | | 1.00 | 1.00 |
| BPJ12 | | | 1.00 | 1.00 |

Notes:
1. Normalized by no-jetty condition values for each wave condition.

Table H7. Optimization Phase current U-velocities in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 1.19 | 1.10 | 1.07 | 1.09 |
| BPJ10 | | | 1.30 | 1.22 | 1.19 | 1.27 |
| BPJ11 | | | 0.94 | 0.97 | 0.94 | 0.96 |
| BPJ12 | | | 0.92 | 0.87 | 0.83 | 0.80 |
| BPJ09 | 34 | 375 | 1.08 | 1.08 | 1.03 | 1.09 |
| BPJ10 | | | 1.15 | 1.12 | 1.11 | 1.16 |
| BPJ11 | | | 1.01 | 0.98 | 1.03 | 1.00 |
| BPJ12 | | | 0.90 | 0.90 | 0.89 | 0.86 |
| BPJ09 | 44 | | 0.98 | 1.02 | 0.98 | 1.01 |
| BPJ10 | | | 1.47 | 1.17 | 1.14 | 1.17 |
| BPJ11 | | | 1.05 | 1.00 | 0.98 | 0.98 |
| BPJ12 | | | 0.89 | 0.91 | 0.86 | 0.85 |
| BPJ09 | 33 | 400 | 1.03 | 1.01 | 1.01 | 0.98 |
| BPJ10 | | | 1.11 | 1.11 | 1.11 | 1.13 |
| BPJ11 | | | 1.08 | 1.01 | 0.95 | 0.94 |
| BPJ12 | | | | 0.89 | 0.88 | 0.82 |
| BPJ09 | 43 | | 1.06 | 1.08 | 1.05 | 1.04 |
| BPJ10 | | | 1.18 | 1.15 | 1.13 | 1.17 |
| BPJ11 | | | 1.07 | 1.01 | 0.98 | 0.98 |
| BPJ12 | | | 0.88 | 0.90 | 0.87 | 0.85 |
| BPJ09 | 32 | 425 | | 1.00 | 0.96 | 1.02 |
| BPJ10 | | | | 1.18 | 1.26 | 1.13 |
| BPJ11 | | | | 0.90 | 0.85 | 0.80 |
| BPJ12 | | | | 0.86 | 0.81 | 0.81 |
| BPJ09 | 42 | | 1.22 | 1.03 | 0.96 | 0.99 |
| BPJ10 | | | 1.21 | 1.19 | 1.15 | 1.19 |
| BPJ11 | | | 1.02 | 1.02 | 1.02 | 0.98 |
| BPJ12 | | | 0.94 | 0.90 | 1.11 | 0.89 |
| BPJ09 | 31 | 450 | | 1.07 | 0.97 | 1.01 |
| BPJ10 | | | 1.22 | 1.03 | 1.00 | 1.06 |
| BPJ11 | | | 0.93 | 0.93 | 0.88 | 0.92 |
| BPJ12 | | | 0.86 | 0.82 | 0.83 | 0.82 |
| BPJ09 | 41 | | 1.11 | 1.09 | 1.02 | 1.02 |
| BPJ10 | | | 1.20 | 1.14 | 1.12 | 1.16 |
| BPJ11 | | | 1.04 | 1.02 | 0.97 | 0.95 |
| BPJ12 | | | 1.04 | 0.90 | 0.87 | 0.83 |

Notes:
1. Blank = Bad or missing data

Table H8. Optimization Phase current V-velocities in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 1.17 | 0.57 | 0.57 | 0.59 |
| BPJ10 | | | 0.91 | 0.70 | 0.78 | 1.04 |
| BPJ11 | | | 0.83 | 0.69 | 0.78 | 0.80 |
| BPJ12 | | | 0.81 | 0.71 | 0.85 | 0.80 |
| BPJ09 | 34 | 375 | 0.59 | 0.53 | 0.66 | 0.64 |
| BPJ10 | | | 0.94 | 0.61 | 0.63 | 0.71 |
| BPJ11 | | | | 0.71 | 0.78 | 0.91 |
| BPJ12 | | | 0.80 | 0.67 | 0.79 | 0.94 |
| BPJ09 | 44 | | 0.58 | 0.49 | 0.56 | 0.59 |
| BPJ10 | | | 1.37 | 0.65 | 0.66 | 0.63 |
| BPJ11 | | | 0.85 | 0.65 | 0.81 | 0.88 |
| BPJ12 | | | | 0.67 | 0.81 | 0.84 |
| BPJ09 | 33 | 400 | | 0.52 | | 0.50 |
| BPJ10 | | | 0.86 | 0.62 | 0.68 | 0.67 |
| BPJ11 | | | 0.86 | 0.64 | 0.72 | 0.80 |
| BPJ12 | | | | 0.67 | 0.70 | 0.82 |
| BPJ09 | 43 | | 0.53 | 0.46 | 0.52 | 0.49 |
| BPJ10 | | | 0.88 | 0.67 | 0.69 | 0.71 |
| BPJ11 | | | 0.81 | 0.66 | 0.73 | |
| BPJ12 | | | 0.84 | 0.70 | | 0.89 |
| BPJ09 | 32 | 425 | | 0.46 | 0.59 | 0.53 |
| BPJ10 | | | | 0.74 | 0.92 | 0.68 |
| BPJ11 | | | 0.88 | 0.57 | 0.63 | 0.72 |
| BPJ12 | | | | 0.61 | 0.84 | 0.65 |
| BPJ09 | 42 | | 0.71 | 0.55 | 0.58 | 0.54 |
| BPJ10 | | | 1.05 | 0.78 | 0.82 | 0.78 |
| BPJ11 | | | 0.91 | 0.68 | 0.80 | 0.86 |
| BPJ12 | | | 0.85 | 0.62 | 0.81 | 0.85 |
| BPJ09 | 31 | 450 | | 0.49 | 0.68 | |
| BPJ10 | | | 1.33 | 0.54 | 0.59 | 0.59 |
| BPJ11 | | | 0.83 | 0.60 | 0.63 | 0.70 |
| BPJ12 | | | 0.83 | 0.64 | 0.59 | 0.67 |
| BPJ09 | 41 | | 0.63 | 0.55 | 0.66 | 0.55 |
| BPJ10 | | | 1.01 | 0.72 | 0.68 | 0.66 |
| BPJ11 | | | 0.90 | 0.79 | 0.77 | 0.81 |
| BPJ12 | | | | 0.60 | 0.73 | 0.81 |
| Notes:<br>1. Blank = Bad or missing data | | | | | | |

Table H9. Optimization Phase current magnitude in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 1.67 | 1.24 | 1.21 | 1.24 |
| BPJ10 | | | 1.58 | 1.40 | 1.42 | 1.64 |
| BPJ11 | | | 1.26 | 1.19 | 1.22 | 1.25 |
| BPJ12 | | | 1.22 | 1.13 | 1.19 | 1.13 |
| BPJ09 | 34 | 375 | 1.23 | 1.20 | 1.22 | 1.26 |
| BPJ10 | | | 1.48 | 1.27 | 1.28 | 1.36 |
| BPJ11 | | | | 1.21 | 1.29 | 1.35 |
| BPJ12 | | | 1.21 | 1.12 | 1.19 | 1.28 |
| BPJ09 | 44 | | 1.14 | 1.13 | 1.13 | 1.17 |
| BPJ10 | | | 2.01 | 1.34 | 1.32 | 1.33 |
| BPJ11 | | | 1.35 | 1.19 | 1.27 | 1.32 |
| BPJ12 | | | | 1.13 | 1.18 | 1.19 |
| BPJ09 | 33 | 400 | | 1.13 | | 1.10 |
| BPJ10 | | | 1.40 | 1.27 | 1.30 | 1.31 |
| BPJ11 | | | 1.38 | 1.19 | 1.19 | 1.24 |
| BPJ12 | | | | 1.11 | 1.12 | 1.16 |
| BPJ09 | 43 | | 1.19 | 1.17 | 1.17 | 1.15 |
| BPJ10 | | | 1.47 | 1.32 | 1.32 | 1.37 |
| BPJ11 | | | 1.34 | 1.20 | 1.22 | |
| BPJ12 | | | 1.22 | 1.14 | | 1.23 |
| BPJ09 | 32 | 425 | | 1.10 | 1.13 | 1.15 |
| BPJ10 | | | | 1.39 | 1.56 | 1.32 |
| BPJ11 | | | | 1.07 | 1.06 | 1.08 |
| BPJ12 | | | | 1.05 | 1.16 | 1.04 |
| BPJ09 | 42 | | 1.41 | 1.17 | 1.12 | 1.13 |
| BPJ10 | | | 1.61 | 1.42 | 1.42 | 1.42 |
| BPJ11 | | | 1.37 | 1.23 | 1.30 | 1.30 |
| BPJ12 | | | 1.27 | 1.10 | 1.38 | 1.23 |
| BPJ09 | 31 | 450 | | 1.17 | 1.18 | |
| BPJ10 | | | 1.81 | 1.17 | 1.17 | 1.22 |
| BPJ11 | | | 1.24 | 1.11 | 1.09 | 1.16 |
| BPJ12 | | | 1.20 | 1.04 | 1.02 | 1.05 |
| BPJ09 | 41 | | 1.27 | 1.22 | 1.21 | 1.16 |
| BPJ10 | | | 1.57 | 1.35 | 1.31 | 1.34 |
| BPJ11 | | | 1.38 | 1.29 | 1.24 | 1.25 |
| BPJ12 | | | | 1.09 | 1.14 | 1.16 |

Notes:
1. Blank = Bad or missing data

Table H10. Optimization Phase average current V-velocity in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 1.17 | 0.57 | 0.57 | 0.59 |
| BPJ10 | | | 0.91 | 0.70 | 0.78 | 1.04 |
| BPJ11 | | | 0.83 | 0.69 | 0.78 | 0.80 |
| BPJ12 | | | 0.81 | 0.71 | 0.85 | 0.80 |
| BPJ09 | 34 & 44 | 375 | 0.59 | 0.51 | 0.61 | 0.61 |
| BPJ10 | | | 1.16 | 0.63 | 0.64 | 0.67 |
| BPJ11 | | | 0.85 | 0.68 | 0.79 | 0.90 |
| BPJ12 | | | 0.80 | 0.67 | 0.80 | 0.89 |
| BPJ09 | 33 & 43 | 400 | 0.53 | 0.49 | 0.52 | 0.49 |
| BPJ10 | | | 0.87 | 0.64 | 0.68 | 0.69 |
| BPJ11 | | | 0.84 | 0.65 | 0.72 | 0.80 |
| BPJ12 | | | 0.84 | 0.68 | 0.70 | 0.86 |
| BPJ09 | 32 & 42 | 425 | 0.71 | 0.50 | 0.58 | 0.54 |
| BPJ10 | | | 1.05 | 0.76 | 0.87 | 0.73 |
| BPJ11 | | | 0.89 | 0.62 | 0.72 | 0.79 |
| BPJ12 | | | 0.85 | 0.62 | 0.82 | 0.75 |
| BPJ09 | 31 & 41 | 450 | 0.63 | 0.52 | 0.67 | 0.55 |
| BPJ10 | | | 1.17 | 0.63 | 0.64 | 0.63 |
| BPJ11 | | | 0.86 | 0.70 | 0.70 | 0.76 |
| BPJ12 | | | 0.83 | 0.62 | 0.66 | 0.74 |

Notes:
1. Blank = Bad or missing data

Table H11. Optimization Phase average current magnitude in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 1.67 | 1.24 | 1.21 | 1.24 |
| BPJ10 | | | 1.58 | 1.40 | 1.42 | 1.64 |
| BPJ11 | | | 1.26 | 1.19 | 1.22 | 1.25 |
| BPJ12 | | | 1.22 | 1.13 | 1.19 | 1.13 |
| BPJ09 | 34 & 44 | 375 | 1.18 | 1.17 | 1.18 | 1.22 |
| BPJ10 | | | 1.75 | 1.31 | 1.30 | 1.34 |
| BPJ11 | | | 1.35 | 1.20 | 1.28 | 1.34 |
| BPJ12 | | | 1.21 | 1.12 | 1.19 | 1.23 |
| BPJ09 | 33 & 43 | 400 | 1.19 | 1.15 | 1.17 | 1.13 |
| BPJ10 | | | 1.44 | 1.30 | 1.31 | 1.34 |
| BPJ11 | | | 1.36 | 1.20 | 1.21 | 1.24 |
| BPJ12 | | | 1.22 | 1.13 | 1.12 | 1.20 |
| BPJ09 | 32 & 42 | 425 | 1.41 | 1.14 | 1.12 | 1.14 |
| BPJ10 | | | 1.61 | 1.41 | 1.49 | 1.37 |
| BPJ11 | | | 1.37 | 1.15 | 1.18 | 1.19 |
| BPJ12 | | | 1.27 | 1.07 | 1.27 | 1.13 |
| BPJ09 | 31 & 41 | 450 | 1.27 | 1.20 | 1.20 | 1.16 |
| BPJ10 | | | 1.69 | 1.26 | 1.24 | 1.28 |
| BPJ11 | | | 1.31 | 1.20 | 1.16 | 1.20 |
| BPJ12 | | | 1.20 | 1.06 | 1.08 | 1.11 |

Notes:
1. Blank = Bad or missing data

Table H12. Optimization Phase normalized current magnitude.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 1.00 | 1.00 | 1.00 | 1.00 |
| BPJ10 | | | 1.00 | 1.00 | 1.00 | 1.00 |
| BPJ11 | | | 1.00 | 1.00 | 1.00 | 1.00 |
| BPJ12 | | | 1.00 | 1.00 | 1.00 | 1.00 |
| BPJ09 | 34 & 44 | 375 | 0.71 | 0.94 | 0.97 | 0.98 |
| BPJ10 | | | 1.10 | 0.93 | 0.91 | 0.82 |
| BPJ11 | | | 1.07 | 1.01 | 1.05 | 1.07 |
| BPJ12 | | | 0.99 | 1.00 | 1.00 | 1.09 |
| BPJ09 | 33 & 43 | 400 | 0.71 | 0.93 | 0.97 | 0.91 |
| BPJ10 | | | 0.91 | 0.92 | 0.92 | 0.82 |
| BPJ11 | | | 1.08 | 1.00 | 0.99 | 0.99 |
| BPJ12 | | | 1.00 | 1.00 | 0.94 | 1.06 |
| BPJ09 | 32 & 42 | 425 | 0.85 | 0.91 | 0.93 | 0.92 |
| BPJ10 | | | 1.01 | 1.00 | 1.05 | 0.83 |
| BPJ11 | | | 1.09 | 0.96 | 0.97 | 0.95 |
| BPJ12 | | | 1.03 | 0.95 | 1.07 | 1.00 |
| BPJ09 | 31 & 41 | 450 | 0.77 | 0.96 | 0.99 | 0.94 |
| BPJ10 | | | 1.07 | 0.90 | 0.87 | 0.78 |
| BPJ11 | | | 1.04 | 1.01 | 0.95 | 0.96 |
| BPJ12 | | | 0.98 | 0.94 | 0.91 | 0.98 |
| Notes:<br>1. Blank = Bad or missing data | | | | | | |

Table H13. Optimization Phase bad current meter data summary.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | XS1,YS1 | XS1,YS1 | | YS3 |
| BPJ10 | | | XS1,YS1 | YS2 | YS1 | XS1,YS1 |
| BPJ11 | | | | | | YS1 |
| BPJ12 | | | | YS2 | | YS1 |
| BPJ09 | 34 | 375 | YS2 | XS1,YS2 | XS1,YS1 | XS2,YS2 |
| BPJ10 | | | | | | |
| BPJ11 | | | YN10 | | YS2 | XS1 |
| BPJ12 | | | YS1 | | | |
| BPJ09 | 44 | | | | | XS1,YS1 |
| BPJ10 | | | XS2,YS2 | | | |
| BPJ11 | | | YS1 | | | |
| BPJ12 | | | YN5 | | | |
| BPJ09 | 33 | 400 | XS2,YS4 | YS1 | XS2,YS2 | |
| BPJ10 | | | | | | |
| BPJ11 | | | XS1,YS1 | | | |
| BPJ12 | | | XS9,YS9 | | | |
| BPJ09 | 43 | | | | | YS2 |
| BPJ10 | | | | | | |
| BPJ11 | | | | | | YS7 |
| BPJ12 | | | | | YS6 | |
| BPJ09 | 32 | 425 | XS11,YS11 | | | |
| BPJ10 | | | XS9,YS5 | YS4 | XS1,YS1 | |
| BPJ11 | | | XS5 | YS1 | | |
| BPJ12 | | | XS3,YS2,YL3 | | | |
| BPJ09 | 42 | | XS1 | | | |
| BPJ10 | | | | | | |
| BPJ11 | | | | | | |
| BPJ12 | | | | | XS2,YS2 | |
| BPJ09 | 31 | 450 | XS4,YS1 | | | YS4 |
| BPJ10 | | | XS2,YS1 | | | |
| BPJ11 | | | YS2 | | | |
| BPJ12 | | | YS1 | YS2 | | |
| BPJ09 | 41 | | | | XS1 | |
| BPJ10 | | | | | | |
| BPJ11 | | | | | | |
| BPJ12 | | | XS1,YN10 | | | |

Notes:
1. Blank = Good data, red color = caution with these data
2. X = x-velocity, Y = y-velocity, S = spike, N = noise or beat in series, L = low values
3. Xx = # occurrences

# Appendix I: Even-Odd Analysis Data

Table I1. Optimization Phase current magnitude change in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 | 375 | -0.44 | -0.04 | 0.01 | 0.03 |
| BPJ10 | | | -0.10 | -0.13 | -0.15 | -0.29 |
| BPJ11 | | | | 0.02 | 0.07 | 0.10 |
| BPJ12 | | | -0.02 | -0.01 | 0.00 | 0.15 |
| BPJ09 | 44 | | -0.53 | -0.11 | -0.08 | -0.07 |
| BPJ10 | | | 0.43 | -0.07 | -0.11 | -0.31 |
| BPJ11 | | | 0.09 | 0.00 | 0.05 | 0.07 |
| BPJ12 | | | | 0.00 | -0.01 | 0.06 |
| BPJ09 | 33 | 400 | | -0.11 | | -0.13 |
| BPJ10 | | | -0.19 | -0.13 | -0.13 | -0.33 |
| BPJ11 | | | 0.12 | 0.00 | -0.03 | -0.01 |
| BPJ12 | | | | -0.02 | -0.07 | 0.03 |
| BPJ09 | 43 | | -0.48 | -0.07 | -0.04 | -0.08 |
| BPJ10 | | | -0.11 | -0.08 | -0.10 | -0.28 |
| BPJ11 | | | 0.08 | 0.01 | 0.01 | |
| BPJ12 | | | -0.01 | 0.02 | | 0.10 |
| BPJ09 | 32 | 425 | | -0.14 | -0.08 | -0.09 |
| BPJ10 | | | | -0.01 | 0.14 | -0.32 |
| BPJ11 | | | | -0.13 | -0.16 | -0.17 |
| BPJ12 | | | | -0.08 | -0.03 | -0.09 |
| BPJ09 | 42 | | -0.25 | -0.08 | -0.09 | -0.10 |
| BPJ10 | | | 0.02 | 0.02 | -0.01 | -0.22 |
| BPJ11 | | | 0.11 | 0.04 | 0.08 | 0.05 |
| BPJ12 | | | 0.04 | -0.03 | 0.19 | 0.10 |
| BPJ09 | 31 | 450 | | -0.07 | -0.03 | |
| BPJ10 | | | 0.22 | -0.24 | -0.26 | -0.43 |
| BPJ11 | | | -0.02 | -0.08 | -0.13 | -0.09 |
| BPJ12 | | | -0.03 | -0.09 | -0.17 | -0.08 |
| BPJ09 | 41 | | -0.39 | -0.02 | 0.00 | -0.08 |
| BPJ10 | | | -0.02 | -0.05 | -0.11 | -0.30 |
| BPJ11 | | | 0.12 | 0.10 | 0.02 | 0.00 |
| BPJ12 | | | | -0.04 | -0.05 | 0.03 |

Notes:
1. Blank = Bad or missing data

Table I2. Optimization Phase average current magnitude change in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 & 44 | 375 | -0.48 | -0.08 | -0.03 | -0.02 |
| BPJ10 | | | 0.16 | -0.10 | -0.13 | -0.30 |
| BPJ11 | | | 0.09 | 0.01 | 0.06 | 0.09 |
| BPJ12 | | | -0.02 | 0.00 | 0.00 | 0.10 |
| BPJ09 | 33 & 43 | 400 | -0.48 | -0.09 | -0.04 | -0.11 |
| BPJ10 | | | -0.15 | -0.11 | -0.11 | -0.30 |
| BPJ11 | | | 0.10 | 0.00 | -0.01 | -0.01 |
| BPJ12 | | | -0.01 | 0.00 | -0.07 | 0.07 |
| BPJ09 | 32 & 42 | 425 | -0.25 | -0.11 | -0.09 | -0.10 |
| BPJ10 | | | 0.02 | 0.00 | 0.07 | -0.27 |
| BPJ11 | | | 0.11 | -0.05 | -0.04 | -0.06 |
| BPJ12 | | | 0.04 | -0.05 | 0.08 | 0.00 |
| BPJ09 | 31 & 41 | 450 | -0.39 | -0.05 | -0.01 | -0.08 |
| BPJ10 | | | 0.10 | -0.15 | -0.19 | -0.36 |
| BPJ11 | | | 0.05 | 0.01 | -0.06 | -0.05 |
| BPJ12 | | | -0.03 | -0.07 | -0.11 | -0.02 |

Notes:
1. Blank = Bad or missing data

Table I3. Optimization Phase current magnitude even component in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 & 44 | 375 | -0.25 | -0.06 | -0.06 | -0.25 |
| BPJ10 | | | -0.07 | -0.11 | -0.11 | -0.07 |
| BPJ11 | | | 0.09 | 0.03 | 0.03 | 0.09 |
| BPJ12 | | | 0.04 | 0.00 | 0.00 | 0.04 |
| BPJ09 | 33 & 43 | 400 | -0.29 | -0.06 | -0.06 | -0.29 |
| BPJ10 | | | -0.23 | -0.11 | -0.11 | -0.23 |
| BPJ11 | | | 0.05 | 0.00 | 0.00 | 0.05 |
| BPJ12 | | | 0.03 | -0.03 | -0.03 | 0.03 |
| BPJ09 | 32 & 42 | 425 | -0.17 | -0.10 | -0.10 | -0.17 |
| BPJ10 | | | -0.13 | 0.04 | 0.04 | -0.13 |
| BPJ11 | | | 0.02 | -0.04 | -0.04 | 0.02 |
| BPJ12 | | | 0.02 | 0.01 | 0.01 | 0.02 |
| BPJ09 | 31 & 41 | 450 | -0.23 | -0.03 | -0.03 | -0.23 |
| BPJ10 | | | -0.13 | -0.17 | -0.17 | -0.13 |
| BPJ11 | | | 0.00 | -0.02 | -0.02 | 0.00 |
| BPJ12 | | | -0.03 | -0.09 | -0.09 | -0.03 |

Notes:
1. Blank = Bad or missing data

Table I4. Optimization Phase current magnitude odd components in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 & 44 | 375 | -0.23 | -0.02 | 0.02 | 0.23 |
| BPJ10 | | | 0.23 | 0.01 | -0.01 | -0.23 |
| BPJ11 | | | 0.00 | -0.03 | 0.03 | 0.00 |
| BPJ12 | | | -0.06 | 0.00 | 0.00 | 0.06 |
| BPJ09 | 33 & 43 | 400 | -0.18 | -0.03 | 0.03 | 0.18 |
| BPJ10 | | | 0.08 | 0.00 | 0.00 | -0.08 |
| BPJ11 | | | 0.06 | 0.01 | -0.01 | -0.06 |
| BPJ12 | | | -0.04 | 0.03 | -0.03 | 0.04 |
| BPJ09 | 32 & 42 | 425 | -0.08 | -0.01 | 0.01 | 0.08 |
| BPJ10 | | | 0.15 | -0.03 | 0.03 | -0.15 |
| BPJ11 | | | 0.08 | 0.00 | 0.00 | -0.08 |
| BPJ12 | | | 0.02 | -0.07 | 0.07 | -0.02 |
| BPJ09 | 31 & 41 | 450 | -0.16 | -0.02 | 0.02 | 0.16 |
| BPJ10 | | | 0.23 | 0.02 | -0.02 | -0.23 |
| BPJ11 | | | 0.05 | 0.03 | -0.03 | -0.05 |
| BPJ12 | | | 0.00 | 0.02 | -0.02 | 0.00 |
| Notes:<br>1. Blank = Bad or missing data | | | | | | |

Table I5. Optimization Phase average even-odd magnitude components in knots.

| Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|
| | 300 | 350 | 400 | 450 |
| Even Components | | | | |
| 375 | -0.05 | -0.03 | -0.03 | -0.05 |
| 400 | -0.11 | -0.05 | -0.05 | -0.11 |
| 425 | -0.06 | -0.02 | -0.02 | -0.06 |
| 450 | -0.10 | -0.08 | -0.08 | -0.10 |
| Odd Components | | | | |
| 375 | -0.01 | -0.01 | 0.01 | 0.01 |
| 400 | -0.02 | 0.00 | 0.00 | 0.02 |
| 425 | 0.04 | -0.03 | 0.03 | -0.04 |
| 450 | 0.03 | 0.01 | -0.01 | -0.03 |
| Notes:<br>1. Blank = Bad or missing data | | | | |

Table I6. Optimization Phase current V-velocity change in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 | 375 | -0.57 | -0.05 | 0.08 | 0.05 |
| BPJ10 | | | 0.03 | -0.09 | -0.15 | -0.33 |
| BPJ11 | | | | 0.02 | 0.00 | 0.11 |
| BPJ12 | | | -0.01 | -0.05 | -0.07 | 0.14 |
| BPJ09 | 44 | | -0.59 | -0.08 | -0.01 | 0.00 |
| BPJ10 | | | 0.46 | -0.05 | -0.12 | -0.41 |
| BPJ11 | | | 0.02 | -0.04 | 0.03 | 0.09 |
| BPJ12 | | | | -0.05 | -0.04 | 0.05 |
| BPJ09 | 33 | 400 | | -0.06 | | -0.09 |
| BPJ10 | | | -0.06 | -0.08 | -0.10 | -0.37 |
| BPJ11 | | | 0.03 | -0.05 | -0.06 | 0.01 |
| BPJ12 | | | | -0.05 | -0.15 | 0.03 |
| BPJ09 | 43 | | -0.64 | -0.11 | -0.05 | -0.10 |
| BPJ10 | | | -0.03 | -0.03 | -0.09 | -0.33 |
| BPJ11 | | | -0.03 | -0.03 | -0.05 | |
| BPJ12 | | | 0.04 | -0.01 | | 0.10 |
| BPJ09 | 32 | 425 | | -0.12 | 0.02 | -0.06 |
| BPJ10 | | | | 0.04 | 0.14 | -0.37 |
| BPJ11 | | | 0.04 | -0.12 | -0.15 | -0.08 |
| BPJ12 | | | | -0.10 | -0.02 | -0.14 |
| BPJ09 | 42 | | -0.45 | -0.03 | 0.01 | -0.05 |
| BPJ10 | | | 0.14 | 0.08 | 0.04 | -0.26 |
| BPJ11 | | | 0.08 | -0.01 | 0.03 | 0.06 |
| BPJ12 | | | 0.04 | -0.09 | -0.04 | 0.06 |
| BPJ09 | 31 | 450 | | -0.08 | 0.11 | |
| BPJ10 | | | 0.42 | -0.16 | -0.19 | -0.45 |
| BPJ11 | | | -0.01 | -0.09 | -0.14 | -0.10 |
| BPJ12 | | | 0.02 | -0.08 | -0.26 | -0.13 |
| BPJ09 | 41 | | -0.54 | -0.02 | 0.09 | -0.04 |
| BPJ10 | | | 0.10 | 0.02 | -0.10 | -0.38 |
| BPJ11 | | | 0.07 | 0.10 | -0.01 | 0.01 |
| BPJ12 | | | | -0.11 | -0.12 | 0.02 |

Notes:
1. Blank = Bad or missing data

Table I7. Optimization Phase average current V-velocity change in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 & 44 | 375 | -0.58 | -0.06 | 0.038 | 0.025 |
| BPJ10 | | | 0.247 | -0.07 | -0.14 | -0.37 |
| BPJ11 | | | 0.018 | -0.01 | 0.017 | 0.099 |
| BPJ12 | | | -0.01 | -0.05 | -0.06 | 0.094 |
| BPJ09 | 33 & 43 | 400 | -0.64 | -0.08 | -0.05 | -0.10 |
| BPJ10 | | | -0.04 | -0.06 | -0.10 | -0.35 |
| BPJ11 | | | 0.00 | -0.04 | -0.05 | 0.01 |
| BPJ12 | | | 0.04 | -0.03 | -0.15 | 0.06 |
| BPJ09 | 32 & 42 | 425 | -0.45 | -0.07 | 0.011 | -0.05 |
| BPJ10 | | | 0.142 | 0.059 | 0.09 | -0.31 |
| BPJ11 | | | 0.058 | -0.07 | -0.06 | -0.01 |
| BPJ12 | | | 0.042 | -0.1 | -0.03 | -0.04 |
| BPJ09 | 31 & 41 | 450 | -0.54 | -0.05 | 0.096 | -0.04 |
| BPJ10 | | | 0.263 | -0.07 | -0.14 | -0.42 |
| BPJ11 | | | 0.03 | 0.007 | -0.07 | -0.04 |
| BPJ12 | | | 0.022 | -0.1 | -0.19 | -0.06 |

Notes:
1. Blank = Bad or missing data

Table I8. Optimization Phase current V-velocity even component in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 & 44 | 375 | -0.28 | -0.01 | -0.01 | -0.28 |
| BPJ10 | | | -0.06 | -0.11 | -0.11 | -0.06 |
| BPJ11 | | | 0.06 | 0.00 | 0.00 | 0.06 |
| BPJ12 | | | 0.04 | -0.05 | -0.05 | 0.04 |
| BPJ09 | 33 & 43 | 400 | -0.37 | -0.07 | -0.07 | -0.37 |
| BPJ10 | | | -0.20 | -0.08 | -0.08 | -0.20 |
| BPJ11 | | | 0.00 | -0.05 | -0.05 | 0.00 |
| BPJ12 | | | 0.05 | -0.09 | -0.09 | 0.05 |
| BPJ09 | 32 & 42 | 425 | -0.25 | -0.03 | -0.03 | -0.25 |
| BPJ10 | | | -0.09 | 0.07 | 0.07 | -0.09 |
| BPJ11 | | | 0.02 | -0.06 | -0.06 | 0.02 |
| BPJ12 | | | 0.00 | -0.06 | -0.06 | 0.00 |
| BPJ09 | 31 & 41 | 450 | -0.29 | 0.02 | 0.02 | -0.29 |
| BPJ10 | | | -0.08 | -0.11 | -0.11 | -0.08 |
| BPJ11 | | | -0.01 | -0.03 | -0.03 | -0.01 |
| BPJ12 | | | -0.02 | -0.14 | -0.14 | -0.02 |

Notes:
1. Blank = Bad or missing data

Table I9. Optimization Phase current V-velocity odd components in knots.

| Signal | Run | Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|---|---|
| | | | 300 | 350 | 400 | 450 |
| BPJ09 | 35 | No | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ10 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ11 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ12 | | | 0.00 | 0.00 | 0.00 | 0.00 |
| BPJ09 | 34 & 44 | 375 | -0.30 | -0.05 | 0.05 | 0.30 |
| BPJ10 | | | 0.31 | 0.03 | -0.03 | -0.31 |
| BPJ11 | | | -0.04 | -0.01 | 0.01 | 0.04 |
| BPJ12 | | | -0.05 | 0.00 | 0.00 | 0.05 |
| BPJ09 | 33 & 43 | 400 | -0.27 | -0.02 | 0.02 | 0.27 |
| BPJ10 | | | 0.15 | 0.02 | -0.02 | -0.15 |
| BPJ11 | | | 0.00 | 0.01 | -0.01 | 0.00 |
| BPJ12 | | | -0.01 | 0.06 | -0.06 | 0.01 |
| BPJ09 | 32 & 42 | 425 | -0.20 | -0.04 | 0.04 | 0.20 |
| BPJ10 | | | 0.23 | -0.02 | 0.02 | -0.23 |
| BPJ11 | | | 0.03 | 0.00 | 0.00 | -0.03 |
| BPJ12 | | | 0.04 | -0.03 | 0.03 | -0.04 |
| BPJ09 | 31 & 41 | 450 | -0.25 | -0.07 | 0.07 | 0.25 |
| BPJ10 | | | 0.34 | 0.04 | -0.04 | -0.34 |
| BPJ11 | | | 0.04 | 0.04 | -0.04 | -0.04 |
| BPJ12 | | | 0.04 | 0.05 | -0.05 | -0.04 |
| Notes:<br>1. Blank = Bad or missing data | | | | | | |

Table I10. Optimization Phase average even-odd V-velocity components in knots.

| Jetty | Current Meter Location, ft | | | |
|---|---|---|---|---|
| | 300 | 350 | 400 | 450 |
| Even Components | | | | |
| 375 | -0.06 | -0.04 | -0.04 | -0.06 |
| 400 | -0.13 | -0.07 | -0.07 | -0.13 |
| 425 | -0.08 | -0.02 | -0.02 | -0.08 |
| 450 | -0.10 | -0.06 | -0.06 | -0.10 |
| Odd Components | | | | |
| 375 | -0.02 | -0.01 | 0.01 | 0.02 |
| 400 | -0.03 | 0.02 | -0.02 | 0.03 |
| 425 | 0.03 | -0.02 | 0.02 | -0.03 |
| 450 | 0.04 | 0.01 | -0.01 | -0.04 |
| Notes:<br>1. Blank = Bad or missing data | | | | |

# Appendix J: Production Phase Ship Speed Data

Table J1. *President Lincoln* Production Phase measured speeds.

| Case ID | Run | Jetty | Average Velocity, kts | | |
|---|---|---|---|---|---|
| | | | In | Out | Average |
| Wave Direction S80W | | | | | |
| BPJ09 | 12 | No | 5.71 | 5.07 | 5.39 |
| BPJ10 | | | 5.28 | 4.51 | 4.90 |
| BPJ11 | | | 5.51 | 4.38 | 4.95 |
| BPJ12 | | | 5.43 | 4.45 | 4.94 |
| BPJ12R5 | | | 5.76 | 4.30 | 5.03 |
| BPJ09 | 14 | 450 ft | 4.88 | 4.35 | 4.65 |
| BPJ10 | | | 5.52 | 4.74 | 5.13 |
| BPJ11 | | | 5.58 | 4.80 | 5.19 |
| BPJ12 | | | 5.79 | 5.10 | 5.45 |

Table J2. *Bunga Saga Empat* Production Phase measured speeds.

| Case ID | Run | Jetty | Average Velocity, kts | | |
|---|---|---|---|---|---|
| | | | In | Out | Average |
| Wave Direction S25W | | | | | |
| BPJ09 | 21 | No | 6.42 | 5.21 | 5.81 |
| BPJ10 | | | 6.38 | 5.40 | 5.89 |
| BPJ11 | | | 6.37 | 5.40 | 5.88 |
| BPJ12 | | | 6.70 | 5.31 | 6.01 |
| BPJ09 | 23 | 450 | 5.93 | 5.15 | 5.54 |
| BPJ10 | | | 6.17 | 5.35 | 5.76 |
| BPJ11 | | | 6.21 | 5.51 | 5.86 |
| BPJ12 | | | 6.02 | 5.55 | 5.79 |
| Wave Direction S80W | | | | | |
| BPJ09 | 11 | No | 5.80 | 4.31 | 5.06 |
| BPJ10 | | | 6.03 | 4.76 | 5.39 |
| BPJ11 | | | 5.71 | 4.79 | 5.25 |
| BPJ12 | | | 5.93 | 4.76 | 5.43 |
| BPJ12R5 | | | 5.85 | 4.46 | 5.16 |
| BPJ09 | 17 | 225 | 5.67 | 4.97 | 5.32 |
| BPJ10 | | | 5.72 | 5.05 | 5.38 |
| BPJ11 | | | 5.96 | 5.16 | 5.56 |
| BPJ12 | | | 6.00 | 5.14 | 5.63 |
| BPJ09 | 15 | 450 | 6.33 | 4.94 | 5.64 |
| BPJ10 | | | 6.08 | 5.25 | 5.66 |
| BPJ11 | | | 5.79 | 5.32 | 5.56 |
| BPJ12 | | | 6.27 | 5.47 | 5.87 |

Table J3. *Kukahi* barge Production Phase measured speeds.

| Case ID | Run | Jetty | Average Velocity, kts | | |
|---|---|---|---|---|---|
| | | | In | Out | Average |
| Wave Direction S25W | | | | | |
| BPJ09 | 27 | No | 3.69 | 3.67 | 3.68 |
| BPJ10 | | | 3.78 | 3.93 | 3.85 |
| BPJ11 | | | 3.86 | 3.83 | 3.84 |
| BPJ12 | | | 3.94 | 3.94 | 3.94 |
| BPJ09 | 29 | 450 | 3.23 | 3.71 | 3.44 |
| BPJ10 | | | 3.72 | 3.28 | 3.50 |
| BPJ11 | | | 3.46 | 3.92 | 3.66 |
| BPJ12 | | | 3.19 | 3.85 | 3.47 |
| Wave Direction S80W | | | | | |
| BPJ09 | 13 | No | 3.29 | 3.30 | 3.29 |
| BPJ10 | | | 3.52 | 3.28 | 3.40 |
| BPJ11 | | | 3.40 | 3.42 | 3.41 |
| BPJ12 | | | 3.13 | 3.64 | 3.39 |
| BPJ09 | 19 | 225 | 3.41 | 3.38 | 3.40 |
| BPJ10 | | | 3.59 | 3.45 | 3.52 |
| BPJ11 | | | 3.29 | 3.54 | 3.41 |
| BPJ12 | | | 3.29 | 3.80 | 3.55 |
| BPJ09 | 16 | 450 | 3.29 | 3.34 | 3.31 |
| BPJ10 | | | 3.50 | 3.08 | 3.29 |
| BPJ11 | | | 3.44 | 3.58 | 3.51 |
| BPJ12 | | | 3.31 | 3.60 | 3.46 |

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

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**1. REPORT DATE** *(DD-MM-YYYY)*
November 2008

**2. REPORT TYPE**
Final report

**3. DATES COVERED** *(From - To)*

**4. TITLE AND SUBTITLE**
Barbers Point Harbor, Hawaii, Jetty Modification Study

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Michael J. Briggs and Ivano Melito

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**
Hydraulic Model Study 007TFB

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

**8. PERFORMING ORGANIZATION REPORT NUMBER**

ERDC/CHL TR-08-16

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
U.S. Army Engineer District, Honolulu
Fort Shafter, HI 96858-5440

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

A series of laboratory experiments were conducted for a range of model ships, irregular waves, wave-induced longshore currents, and jetty lengths to optimize the length of a proposed entrance channel jetty at Barbers Point Harbor, Hawaii. Eleven jetty configurations were studied on both sides of the entrance channel, with lengths varying from no-jetty to the proposed 450-ft length. Unidirectional spectral waves with wave periods of 6, 10, 14, and 18 sec, wave height of 7 ft, and incident wave directions of S25W (20 deg south of channel centerline) and S80W (35 deg west of channel centerline) were generated. Wave-induced ship motions were obtained for 392 inbound and outbound transits with 1:75 scale models of the APL *President Lincoln* C9-Class containership, a modified *Bunga Saga Empat* bulk-cargo carrier, and a *Kukahi* oceangoing barge. The 375-ft-long jetty on the north side of the channel and the 2-ft depth transition inside the harbor were recommended. This conclusion was based on (a) measured wave heights in the channel and barge basin, (b) ship and barge handling and maneuverability characteristics, (c) dye and current meter studies of the circulation patterns and flows in the channel, and (d) input from the sponsor, EPA, and harbor pilots.

**15. SUBJECT TERMS**

| | | | |
|---|---|---|---|
| Deep draft navigation | Barbers Point Harbor, Hawaii | Irregular waves | Physical models |
| Entrance channel design | Entrance jetty design | Longshore currents | Model ships |
| | Optimized channel design | Wave-induced ship motions | |

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)* |
|---|---|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | | 179 | |